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THE VESTIBULAR SENSORY EPITHELIA IN THE CAT LABYRINTH AND THEIR REACTIONS IN CHRONIC STREPTOMYCIN INTOXICATION[1]

Jan Wersäll and Joseph E. Hawkins, Jr.[2]
Stockholm, Sweden, and New York, U.S.A.

From the Departments of Otolaryngology and Anatomy, New York University Medical Center, New York, N. Y. and the Departments of Histology and Otolaryngology, Karolinska Institutet, Stockholm, Sweden

Although the toxic action of streptomycin for the mechanisms of posture and equilibrium was revealed in its first clinical trial (Hinshaw & Feldman, 1945) and was soon reproduced in laboratory animals (Molitor *et al.*, 1946) the precise nature of this action is still by no means fully understood. Even the site of the toxic action has been variously assigned to the inner ear, the vestibular nerve and ganglion cells, the vestibular nuclei and the cerebellum (Berg 1949, 1951, Causse *et al.*, 1949, Christensen *et al.*, 1950, 1953, De Kleyn & Van Deinse, 1950, Dix *et al.*, 1949, Floberg *et al.*, 1949, Glorig & Fowler, Jr., 1947, Hawkins Jr., 1947, 1950, Hawkins, Jr. & O'Shanny, 1948, Ruedi *et al.*, 1948, Stevenson *et al.*, 1947, Vanderhaege, 1949, Winston *et al.* 1948). With further study of the toxicity of streptomycin and closely related basic antibiotics (Hawkins, Jr. & Lurie, 1952, 1953, Hawkins, Jr., 1959) the action of streptomycin has been recognized as an example of *ototoxicity* affecting primarily the sensory epithelia of the labyrinth.

The present study attempts to correlate chronic disturbance of vestibular function in streptomycin treated cats with structural changes in the sensory epithelia at cellular and subcellular levels, as revealed by light and electron microscopy. The ultrastructure of the normal labyrinthine sensory epithelia of the cat is also described for the first time.

Cats were chosen for the experiment because they had shown a very uniform reaction to streptomycin in earlier studies. Impairment of vestibular function and degenerative changes in the sensory epithelia are more easily and more regularly produced by the antibiotic in this species than in rabbits, guinea pigs, rats and mice (Hawkins, Jr., 1959).

MATERIAL AND METHODS

Fifteen carefully selected, healthy, young adult cats were used for the experiments. Four of them received streptomycin, as the pantothenate salt, in doses of 400 mg/kg

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[2] Address 1961–62: Department of Otolaryngology, Sahlgrenska Sjukhuset, Göteborg, Sweden.

body weight daily for 16 days Seven others received streptomycin, as the sulphate, in doses of 400, 200 or 100 mg/kg daily for 16 to 40 days (Table I) The remaining four cats served as normal controls All were examined daily during the period of treatment for signs of vestibular disturbance The degree of impairment of function was estimated and rated as follows — normal + slight ataxia confined to hind limbs + + moderate ataxia + + + severe ataxia, occasional head oscillations + + + + unable to walk, severe head oscillations

The animals were observed for eight to eleven months in all No systematic electronystagmographic studies were made, but before the final experimental procedures were carried out, the function of the horizontal canals was tested by rotating each cat on a motor driven turntable Horizontal nystagmus was recorded both during and after rotation by picking up the corneo retinal potential by means of solder disc electrodes pasted to the shaved skin near the other canthi The rhythmic variations in potential between the electrodes during nystagmus were registered after appropriate amplification on an ink writing oscillograph (Hawkins, Jr & O Shanny, 1948 Hawkins, Jr, 1947, 1959) In some of the animals a galvanic test of vestibular function was carried out by passing a weak DC current across the head between two electrodes held against the skin over the temporal bones

The cats were anesthetized with pentobarbital sodium, 35 mg/kg i p After tests of cochlear function had been completed by opening the tympanic bulla and recording the cochlear potentials from the round window, the temporal bones were prepared for either electron or light microscopy In those animals intended for electron microscopy the ossicles were removed The vestibule, the utricle, the horizontal and anterior vertical ampullae were exposed Both the round window and the apex of the cochlea were opened, and 1 % buffered osmium tetroxide solution made isotonic with sodium chloride (Rhodin, 1951) was injected into the perilymphatic spaces The fixative was replaced several times during one-half hour, after which the animal was sacrificed The ampulla and the cochlea were further exposed, and the specimens were fixed in the same cold (+ 1°C) solution for four hours The ampulla and the macula utriculi were dissected free from the surrounding bone and the specimens were rinsed in saline They were then dehydrated in ascending concentrations of alcohol (70 % 12 hours 90 % 1 hour, 96 % 1 hour and absolute alcohol 2 hours) transferred to a mixture of one part methyl methacrylate and 19 parts butyl methacrylate monomer with 1 % benzoyl peroxide as a catalyst (Newman et al 1949), and kept there for two hours with several changes of the mixture Finally, the specimens were embedded in gelatine capsules in the same mixture, prepolymerized to a syrup thick consistency on a water bath at 90 C and cooled down to around 60°, at which temperature they were kept and polymerized for about 18 hours

Sections 0 5 μ thick were cut on a Servall microtome or an LKB Ultrotome and studied with a Zeiss phase contrast microscope Thin sections cut on the same microtomes with glass knives were floated on 20 % acetone and mounted on specimen supports with a single hole 2 mm 1 mm in size covered with formvar films (Ledergren, 1955) The thin sections were studied in a Siemens Elmiskop I or an RCA EMU 2 electron microscope Pictures were taken at a magnification of 1000 or 11 000 times and photographically enlarged to appropriate magnification In order to enhance the contrast in the specimens some of the sections were stained with uranyl nitrate uranyl acetate (Watson 1958 Brody, 1959) by floating the specimen support with the sections down on the surface of saturated solutions of the salts at room temperature or at 45°C for 20 minutes

TABLE 1

No	E M No	Dose mg/kg × days	Onset of ataxia (days)	Total dose mg/kg	Sacr (months post R_x)	Ataxia Max → Final
Cats for electron microscopy						
2137	11	100 × 35 SM sulph	17	3.5	10	4+ → 2+
2131	5	200 × 25 SM sulph	12	5.0	9	4+ → 2+
2160 L	12	200 × 40 SM sulph	13	8.0	8	4+ → 2+
2118	7	400 × 16 SM sulph	1	6.4	11	4+ → 2+
2114	2	400 × 16 SM panth	1	6.4	9.5	4+ → 2+
2119	3	400 × 16 SM panth.	1	6.4	9.5	4+ → 2+
2113	4	400 × 16 SM panth	1	6.4	10	4+ → 2+
2120	10	400 × 16 SM panth.	1	6.4	11	4+ → 2+
2165	8	Normal control	—	—	—	—
2167	15	Normal control	—	—	—	—
Cats for light microscopy						
2122	—	200 × 26 SM sulph	19	5.2	8	3+ → 2+
2160 R	—	200 × 40 SM sulph	13	8.0	8	4+ → 2+
2110	—	400 × 16 SM sulph	1	6.4	7	4+ → 2+
2117	—	400 × 16 SM sulph	1	6.4	7.5	4+ → 2+
2163	—	Normal control	—	—	—	—
2164	—	Normal control	—	—	—	—

The animals intended for light microscopy were sacrificed by perfusing the head by way of the carotids with approximately 500 ml of a solution of 2.5 % gum acacia in saline, followed by an equal amount of a similar solution in 10 % formalin, both solutions being delivered at a hydrostatic pressure of approximately 120 mm Hg (Koenig *et al.*, 1945). After further fixation in Heidenhain's Susa and decalcification with trichloracetic acid, the specimens were dehydrated and embedded in celloidin. They were sectioned transversely in the plane parallel to the modiolus of the cochlea, with the brainstem and cerebellum remaining *in situ* between the two temporal bones. Serial sections were cut at 18 μ. Every tenth section was stained with Masson's trichrome stain, and selected intermediate sections were stained by Reumont's method of silver impregnation as modified by Schuknecht (Reumont, 1931). In one animal (2160) one ear was prepared for electron microscopy and the other for light microscopy.

RESULTS

Physiological Findings

In the cats receiving doses of 100 or 200 mg/kg the vestibular disturbance appeared only after 12 to 19 days of treatment, as a slight incoordination in the movements of the hind limbs. As treatment was continued, the normal righting reflexes gradually were lost. When pushed from a chair the cats were no longer able to land on their feet. The ataxia progressed to the point where they had great difficulty in standing upright. At this late stage their

FIG. 3. Phase contrast picture of section from normal sensory epithelium in the crista ampullaris from a cat. *HC I*, hair cell of type I. The small granules surrounding the hair cell are the mitochondria in the nerve chalice. *HC II*, hair cell of type II; the arrow (→) points towards the nerve endings at the bottom of one hair cell of type II. The small arrows (→) at the surface show basal corpuscles in the cuticle of the hair cells from which a kinocilium protrudes. Observe the difference in density between the kinocilium and the stereocilia in the hair bundle. Cat No. 21[illegible] (2,500 ×).

All the epithelia have an essentially similar structure. They thus consist of three different types of cells: supporting cells and two types of sensory cells or hair cells. The supporting cells rest with their broad basal end containing the ovoid nucleus on the basement membrane. The thin distal part of the cell, which is filled with secretory granules, passes flattened between the sensory cells and nerve fibres up to the surface of the epithelium. Immediately below the surface the cell has a supporting ring of dense substance, resembling the terminal bars in other cells, which forms a rigid supporting structure for the hair cells (Figs. 3, 5).

The hair cells are lodged between the supporting cells and occupy the outer two thirds or more of the epithelium. The hair cells of type I have the form of short flasks with a round bottom, a thin neck and a broader flat surface facing the endolymph. The globular nucleus is found in the basal part of the cell. The hair cells of type II are cylindrical in shape. Their length and the location of their nuclei in the cells varies.

The free surface of each hair cell is covered with a round cuticular plate from which a tuft of sensory hairs reach out into the endolymph. The periphery of the cuticle encloses a basal corpuscle which sends out a cilium of kinocilial structure (Fig. 4). The ground substance of the hair cells consists primarily of granules around 150 Å in diameter, some of which are assembled in clusters of varying size, whereas others are attached to membranous

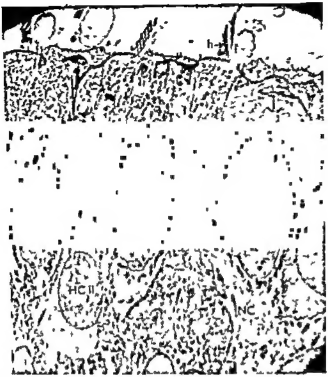


Fig. 4. Electron micrograph from the same area as shown in Fig. 1. The nerve chalice (NC) in this picture encloses two neighboring hair cells type I. Close to the hair bundles (*h*) are found small protoplasmatic protrusions from the hair cells. Cat No. 2165. (3200×.)

formations. The mitochondria in the hair cells are short rod shaped bodies with an average diameter of around 0.3 μ. Each mitochondrion is surrounded by a double membrane and contains a number of inner membranes across the body of the mitochondrion, similar to those found in mitochondria in many other epithelial cells, muscle fibres, etc. (Cedergren, 1959, Sjöstrand, 1953) (Figs. 5, 15, 16). Some small vacuoles and membranes are regularly found in the supranuclear part of the cells.

The nerve fibres innervating the vestibular sensory epithelia are the peripheral myelinated axones of the bipolar vestibular ganglion cells. Each nerve fibre looses its myelin and Schwann sheath in the immediate neighborhood of the basement membrane of the epithelium. The axon branches between the supporting cells in the epithelium. Some branches form nerve chalices enclosing one or sometimes two or three sensory cells of type I (Figs. 4, 5). These chalices cover the body and the neck of the cell and are closely attached to the plasma membrane of the cell. Other nerve branches divide into a great number of nerve terminals, only a few tenths of a micron in diameter. These end on the bottom of hair cells of type II (Fig. 5). Some of these branches also come in close contact with and may end on the outside of nerve chalices.

The fine structure of the axones in the myelinated nerve fibres does not

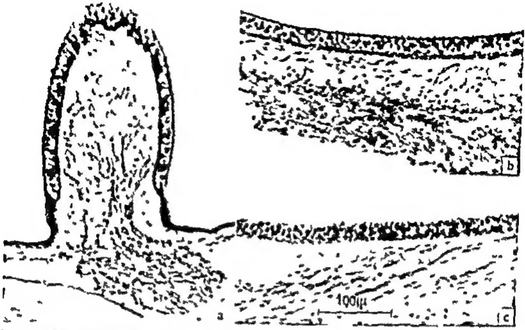


Fig. 8. Crista of the horizontal canal (a), macula of the utricle (b) and saccule (c) in cat 2163, normal control.

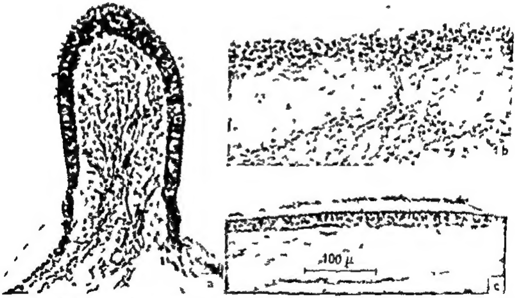


Fig. 9. Crista of the horizontal canal (a), macula of the utricle (b) and saccule (c) in cat 2164, normal control.

epithelium and extensive loss of hair cells, while the supporting cells remain. The utricular macula appears to have suffered somewhat less damage, and the saccular macula least of all.

Some loss of the terminal portion of the nerve fibres is evident, but the degree of loss is difficult to evaluate in the Masson trichrome stained sections.

FIG 10 Crista of the posterior canal showing nerve fibres approaching the neuroepithelium Silver impregnation Cat 2122 8 months after streptomycin sulphate 200 mg/kg daily for 26 days

In silver impregnated sections a few fine nerve fibres could be seen approaching the basement membrane (Fig 10) but only rarely was a fibre seen to enter the neuroepithelium A short distance below the neuroepithelium the nerve fibres present a normal appearance as do the cells of Scarpa s ganglion in the internal meatus

Electron microscopy

Advanced degeneration of the sensory epithelia in the cristae ampullares and the maculae utriculi was found in all streptomycin treated animals in the series No difference was shown in streptomycin sulfate and pantothenate treated animals All hair cells of type I had disappeared in the sections studied Some hair cells of type II had disappeared and other cells of this variety showed signs of degeneration Some of the type II cells had a comparatively normal appearance The nerve chalices had disappeared and only thin nerve branches were seen within the epithelia Many of these branches were of the vesiculated variety In the immediate neighborhood of the epithelium below the basement membrane only very thin unmyelinated nerve fibres were shown which might be true unmyelinated fibres or regenerating axones from myelinated fibres (Figs 11 12) Somewhat thicker regenerating fibres were seen further down in the connective tissue and at a distance of around 30 μ or more from the basement membrane myelinated fibres of normal appearance were observed

Fig 11 Survey picture of a cross section through the crista ampullaris from a cat treated with 400 mg SMP for 10 days In the part of the section visible on the picture only one hair cell of type II is seen The supporting cells with their basally located nuclei are the only cells seen in the rest of the picture The arrows show regenerating nerve fibres Electron micrograph Cat No 2113 Inset higher magnification of the area containing the hair cell of type II visible in the larger picture (1300 × inset 3600 ×)

The most severe changes were found in the cristae ampullares from the animals treated with 400 mg streptomycin and streptomycin pantothenate/kg body weight In these animals only very few hair cells of type II were found along the summit of the cristae A few more cells of the same variety were found on the slopes of the cristae (Figs 11 12) In the macula utriculi the hair cells of type II seemed to be somewhat less affected (Fig 14) In the animals treated with lower doses the type II cells even in the cristae were better preserved

The supporting cells showed no granules of the normal secretory type but contained a great number of dense osmiophilic granules or bodies of varying size The supporting cell nuclei looked normal in appearance and number

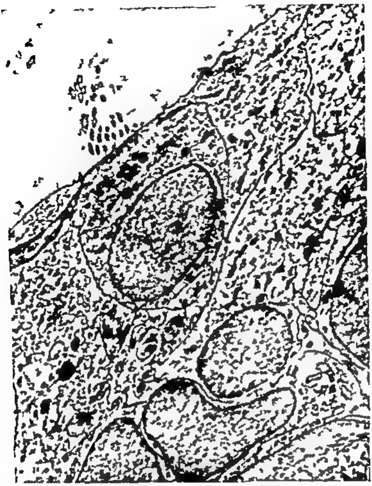


Fig 12 The hair cell of type I from Fig 11 showing a number of dense osmiophilic granules in the supranuclear part of the cell marked with an arrow (→) Compare with mitochondria (↔) The nerve endings on the base of the cell (*NE*) are well preserved as well as a number of thin nerve fibres between the supporting cells Electron micrograph Cat No 2113 (8000 ×)

The hair cells of type II showed a very varying picture Some of the cells had a pyknotic nucleus and a vesiculated very dense cytoplasm The mitochondria present had only very few internal membranes (Fig 13) Other cells contained a large number of osmiophilic bodies but looked otherwise comparatively well preserved The osmiophilic bodies were of varying size from around 0 3 μ up to 0 7 μ Many of these bodies had a lobated appearance others were similar in shape to the mitochondria and showed a few membranous structures in the matrix (Figs 13 15)

In the utricle some hair cells of type II contained a great number of vesicles in the infranuclear part of the cell varying in diameter between 800 Å and 0 2 μ These vesicles sometimes occupied most of the cell body These cells also had a folded nuclear membrane and a pycnotic nucleus (Fig 16)

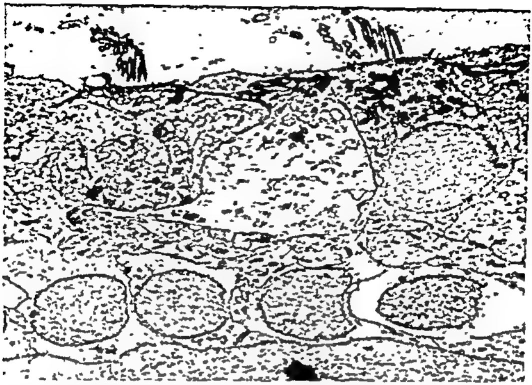


Fig 13 Degenerating sensory cells from another part of the same crista Nu is the pycnotic nucleus of a hair cell of type II which shows a severe degeneration with vacuolization and degeneration of the cytoplasm The other hair cell in the picture contains a couple of osmiophilic granules and some large vesicles but is otherwise rather well preserved A considerable swelling is found in the supporting cells Electron micrograph. Cat No 2113 (5000 ×)

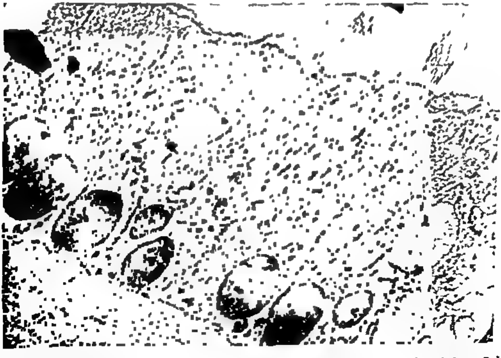


Fig 14 Survey picture from a cat macula utriculi treated with 400 mg SMP for 16 days Only hair cells of type II are present (HC) The nerve endings shown at the arrow at a base of one of these hair cells are well preserved Cat No 2113 (3300 ×)

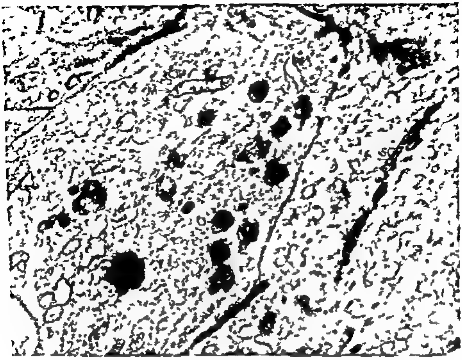
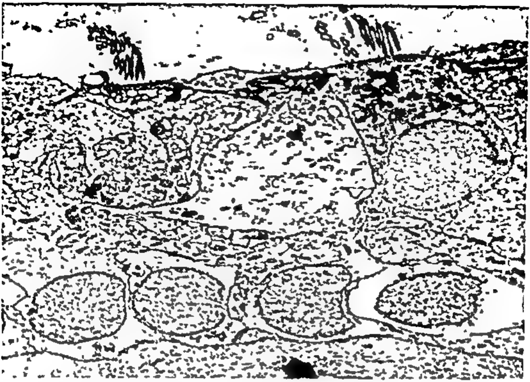


FIG 15 The upper part of a hair cell of type II from the same macula utriculi showing a large number of osmiophilic bodies M, mitochondrion SC, supporting cell Cat No 2113 (16 000 ×)

FIG 16 The basal part of a hair cell of type II from the same macula with surrounding nerve endings The nucleus is pyknotic with a folded nuclear membrane The cell contains a large number of vesicles of varying size The nerve endings (NE) have a normal appearance M_1 mitochondrion in a nerve fibre M_2, in the cell → Vesicles in the cell ↔ synaptic vesicles Cat No 2113 (20,000 ×



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scopy and neighboring sections can be used for electron microscopy and thus make a comparison between the light microscopic and electron microscopic picture possible The large size of the hole in the specimen support used in the study provides a possibility of taking photos of the whole crista and studying serial sections of whole cristae in the electron microscope without the intervening cross bars in the ordinary grids This is extremely important in the study of the present material where only a few well preserved hair cells are left in an otherwise severely damaged tissue

A few disadvantages with the method are present A very careful preparation of the various sensory areas must be done The speed of penetration of the osmium solution is extremely slow The labyrinth thus must be very widely exposed to the fixative to facilitate its passage to the sensory epithelia in order to avoid *post mortem* changes The various parts of the labyrinth are prepared free from the surroundings and the temporal bone cannot be studied as a whole unit on one section

The methods used for phase contrast microscopy are recommended for use even in laboratories where electron microscopes are not available as a complementary method to be used in combination with standard temporal bone histology techniques

Physiology

The physiological findings concerning the behavior of the streptomycin treated cats are in good agreement with those of earlier studies (Ruedi *et al* 1948 Hawkins Jr 1947) The severe ataxia and the lack of post rotatory nystagmus are well explained by the severe damage to the sensory epithelia in the labyrinth It is difficult to say how much of the recovery of vestibular function during the intermediate period between the drug treatment and the time of sacrifice is dependent on recovery of the remaining hair cells and how much is a central adaptation It is not unlikely, however, that some of the remaining hair cells may function This problem must be further studied with direct electrophysiological investigation on the vestibular nerve Such studies are under way

Structural Findings

The normal structure of the cat labyrinth sensory epithelia is very similar to that in the guinea pig (Wersäll 1956 1961 Engström 1958, Engström & Wersäll 1958) rat and mouse (Barrat Jr & Iurato) but differs from that in the ray dogfish (Lowenstein & Wersäll 1961) and fowl otocyst (Friedmann 1959) where only one type of hair cell is present

The severe damage observed in the sensory epithelia in the labyrinth of cats after streptomycin treatment agrees with earlier findings (Berg 1949 1951 Hawkins Jr & Lurie 1952) Equally severe damage was found after treatment with equal doses of either streptomycin sulfate or streptomycin pantothenate as was earlier shown in a comparative study of the effect of these two agents (Hawkins Jr *et al* 1956–1957) Therefore we found no

reason to give separate descriptions of animals treated with the two agents as the changes appeared identical

The hair cells found intact in the earlier light microscopic studies of streptomycin treated cats (Berg 1949 1951 Hawkins Jr & Lurie 1952) were probably of type II like those found in the present study These cells are apparently less sensitive than the type I cells to the destructive action of streptomycin *The reason for this difference in degree of sensitivity is obscure* It seems likely however that the type I cells which are phylogenetically later and more highly differentiated than the type II cells (Wersall 1961) have a higher metabolism and are more easily affected by the antimetabolic action of streptomycin The difference in sensitivity to streptomycin thus *supports an earlier hypothesis that these two cell types have different func*tions (Wersall 1956) It is possible that the studies of the activity in the vestibular nerve of streptomycin treated cats where the hair cells of type I have been destroyed by streptomycin can give more information about the difference in function between the two cell types as suggested above

The changes seen in the sensory epithelia resemble in certain respect those seen in the ear in other forms of degeneration Osmiophilic bodies similar to those seen in the degenerating vestibular epithelium have also been found in the hair cells of the organ of Corti after acoustic trauma (Spoendlin 1958) Although we have seen that the nucleus becomes pyknotic during the later stages of the degeneration the changes observed in the mitochondria and throughout the cytoplasm suggests that streptomycin acts primarily in this *portion of the cell presumably on some factor important for its metabolism* Degeneration of mitochondria and formation of myelin figures was observed recently (Friedmann & Bird 1961) in sensory cells in isolated fowl embryo *otocysts after treatment with streptomycin and other antibiotics* It is possible that the large granules observed in the present study in some remaining cells are late stages of such degenerated mitochondria

The protoplasmatic protrusions observed in the epithelia from some of the animals are not considered as a fixation artefact as suggested by earlier authors (Retzius 1881) Small protrusions of the same type are seen in normal animals (Wersall 1956 Vilstrup 1950) and are probably some type of secretion from the epithelium It is suggested that this movement of cytoplasm from the epithelium to the endolymphatic space *is increased in* the degenerating epithelium in such a way that degenerating cytoplasm to a large extent is pushed out from the epithelium into the surrounding medium Even in the normal animals cytoplasm from hair cells including mitochondria and other cell constituents are included in the growing cupula as has been observed by one of us (J W) in the cat ray and guinea pig

The thicker nerve branches in the epithelium are apparently more sensitive than the fine fibres Whether this is directly related to the early degeneration of the hair cells of type I or is a true difference in sensitivity between two varieties of nerve fibres has to be found out from the acute experiment The fact that a large number of vesiculated nerve fibres are found even in areas

where few sensory cells are present might suggest that these fibres have other functions than the non-vesiculated fibres, for example that they might be efferent, as earlier suggested (Smith 1954).

The peripheral damage in the sensory epithelia in the labyrinth caused by streptomycin is definite and unquestionable. The central vestibular pathways were not studied in this investigation. Several earlier studies (Hawkins Jr. 1959, Vilstrup 1950) have not revealed any central damage in these animals; however, and whatever damage there might be in the central nervous system must be of secondary importance compared with these severe changes demonstrated in the peripheral end organs. A difference among species is however not excluded and a careful analysis is now under way of the guinea pig and its reactions to streptomycin.

The severe changes in the sensory epithelium of the cristae and in the zone of connective tissue under the basement membrane suggest the possibility that streptomycin is concentrated in the endolymph or in the subcupular space and acts locally on the most neighboring structures. The regenerating nerve fibres found below the basement membrane in the recovering animal apparently regenerate from those myelinated fibres found further down in the connective tissue of the crista.

The reason for the more severe damage in the cristae as compared with the macula utriculi is not known. It is suggested that the streptomycin is concentrated in the endolymph through an active secretion by the secretory cells in the crista and thus reaches a high concentration in the subcupular space. Some of the streptomycin diffuses out through the cupula or is secreted by secretory cells in the utricle and reaches the macula utriculi but at a lower concentration than in the crista.

The early changes in the sensory epithelia in the labyrinth after streptomycin treatment will be discussed in a later paper.

SUMMARY

The effect of streptomycin on the sensory epithelia in the vestibular part of the labyrinth in cats was studied by means of electronystagmography, light microscopy, phase contrast microscopy and electron microscopy.

High doses of streptomycin sulfate and streptomycin pantothenate were administered subcutaneously to cats until a severe ataxia and total loss of nystagmus appeared.

The animals were allowed to recover for eight to eleven months, after which they were sacrificed. The changes in the sensory epithelia of the cristae ampullares and the maculae utriculi were studied by standard histological methods and by means of phase contrast microscopy and electron microscopy on material fixed with osmium tetroxide and embedded in methacrylate.

The normal vestibular sensory epithelia in cats were found to contain the same structural elements as in guinea pigs, rats and mice, that is, two types of hair cells and supporting cells. A short description of these cell types and their innervation is given.

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The peripheral damage in the sensory epithelia in the labyrinth caused by streptomycin is definite and unquestionable The central vestibular pathways were not studied in this investigation Several earlier studies (Hawkins Jr 1959 Vilstrup 1950) have not revealed any central damage in these animals however and whatever damage there might be in the central nervous system must be of secondary importance compared with these severe changes demonstrated in the peripheral end organs A difference among species is however not excluded and a careful analysis is now under way of the guinea pig and its reactions to streptomycin

The severe changes in the sensory epithelium of the cristae and in the zone of connective tissue under the basement membrane suggest the possibility that streptomycin is concentrated in the endolymph or in the sub cupular space and acts locally on the most neighboring structures The re generating nerve fibres found below the basement membrane in the re covering animal apparently regenerate from those myelinated fibres found further down in the connective tissue of the crista

The reason for the more severe damage in the cristae as compared with the macula utriculi is not known It is suggested that the streptomycin is concentrated in the endolymph through an active secretion by the secretory cells in the crista and thus reaches a high concentration in the subcupular space Some of the streptomycin diffuses out through the cupula or is secreted by secretory cells in the utricle and reaches the macula utriculi but at a lower concentration than in the crista

The early changes in the sensory epithelia in the labyrinth after strepto mycin treatment will be discussed in a later paper

SUMMARY

The effect of streptomycin on the sensory epithelia in the vestibular part of the labyrinth in cats was studied by means of electronystagmography light microscopy, phase contrast microscopy and electron microscopy

High doses of streptomycin sulfate and streptomycin pantothenate were admi nistered subcutaneously to cats until a severe ataxia and total loss of nystagmus appeared

The animals were allowed to recover for eight to eleven months after which they were sacrificed The changes in the sensory epithelia of the cristae ampullares and the maculae utriculi were studied by standard histological methods and by means of phase contrast microscopy and electron microscopy on material fixed with osmium tetroxide and embedded in methacrylate

The normal vestibular sensory epithelia in cats were found to contain the same structural elements as in guinea pigs rats and mice that is two types of hair cells and supporting cells A short description of these cell types and their innervation is given

Severe damage was observed in the vestibular sensory epithelia of all treated animals A complete degeneration of the type I hair cells was found and various stages of degenerative change in the hair cells of type II and supporting cells These degenerative changes included the appearance of a large number of osmiophilic inclusions in the supranuclear parts of the hair cells, pyknosis of the nuclei, swelling and vacuolization of the cytoplasm, and appearance of large protoplasmic protrusions from some of the hair cells The secretory granules disappeared in the supporting cells and osmiophilic bodies appeared even in those cells

The difference in sensitivity for streptomycin intoxication between the hair cells of type I and type II suggests a difference in function and metabolic activity between these cells

The thin vesiculated nerve fibres were more resistant to streptomycin intoxication than the thicker fibres and the nerve chalices, which disappeared during the treatment

It is suggested that streptomycin is secreted through the secretory cells in the cristae *and has a local effect on the sensory epithelia in the labyrinth*

No difference is found in the ototoxic effect of streptomycin pantothenate as compared with streptomycin sulfate

There is a good correlation between the severe disturbance of the equilibratory mechanism and the damage in the sensory epithelia in the peripheral sensory apparatus, supporting earlier suggestions that the effect of streptomycin in cats is mainly *if not exclusively peripheral*

ZUSAMMENFASSUNG

Die Wirkung von Streptomycin auf das Sinnesepithel im vestibularen Teil des Labyrinths bei Katzen wurde mit Hilfe von Elektronystagmographie, optischer Mikroskopie, Phasenkontrastmikroskopie und Elektronenmikroskopie untersucht

Hohe Dosen von Streptomycin Sulfat und Streptomycin Pantothenat wurden den Katzen subcutan gegeben, bis schwere Ataxie und ein vollstandiger Verlust von Nystagmus eintrat

Nach acht bis elf Monaten Genesungszeit wurden die Tiere getotet Die Veranderungen im Sinnesepithel der Cristae ampullares und der Maculae utriculi wurde mittels histologischer Standardmethoden und mit Hilfe des Phasenkontrastverfahrens und der Elektronenmikroskopie untersucht, wobei das Material mit Osmium Tetroxid fixiert und in Methacrylat eingelegt worden war

Es erwies sich, dass das normale vestibulare Sinnesepithel bei Katzen die gleichen strukturellen Elemente enthielt wie bei Meerschweinchen, Ratten und Mausen, d h zwei Arten von Haarzellen und Unterlagezellen Eine kurze Beschreibung dieser Zelltypen und ihrer Innervation wird gegeben

Schwerer Schaden wurde im vestibularen Sinnesepithel aller behandelten Tiere festgestellt Es zeigten sich eine vollstandige Degeneration der Haarzellen von Typ I und verschiedene Stadien degenerativer Veranderung bei den Haarzellen von Typ II und den Unterlagezellen Die degenerativen Veranderungen umfassen das Auftreten einer grossen Anzahl osmiophiler Einschlusse in den supranuclearen Teilen der Haarzellen, Pyknose der Zellkerne, Anschwellung und vakuolare Degeneration des Zytoplasmas und Erscheinung grosser protoplasmischer Auswuchse aus einigen Haarzellen Die sekretorischen Granulae verschwanden in den Unterlagezellen und osmiophile Teilchen erschienen auch hier

Der Unterschied in der Empfindlichkeit für Streptomycinintoxikation zwischen den Haarzellen von Typ I und von Typ II deutet auf einen Unterschied hinsichtlich der Funktion und metabolischen Tätigkeit zwischen diesen Zelltypen hin

Die dünnen vesikulierten Nervenfasern waren widerstandsfähiger gegen Streptomycinintoxikation als die dickeren Fasern und die Nervencalices, welche während der Behandlung verschwunden waren

Es wird angenommen, dass das Streptomycin durch die Sekretzellen in den Cristae ausgesondert wird und eine örtliche Wirkung auf das Sinnesepithel im Labyrinth ausübt

Die ototoxische Wirkung von Streptomycin Pantothenat unterschied sich nicht von der des Streptomycin Sulfats

Es besteht ein deutlicher Zusammenhang zwischen der schweren Störung des Gleichgewichtsmechanismus und der Beschädigung des Sinnesepithels im peripheren Sinnesapparat, was frühere Vermutungen bekräftigt, dass die Wirkung von Streptomycin bei Katzen hauptsächlich, wenn nicht sogar ausschliesslich, peripher sei

ACKNOWLEDGEMENTS

Part of the study was made when Dr Wersall held a visiting lectureship in the Department of Otolaryngology, New York University Medical Center Sincere appreciation is expressed to Dr John F Daly, head of the Department of Otolaryngology, for his constant interest and support of the investigation The authors are grateful also to Dr Harry J Robinson, Director of the Merck Institute for Therapeutic Research, Rahway, New Jersey, for permission to use his laboratories, where treatment and physiological tests of the cats were carried out They acknowledge the technical assistance of Mr Walter J O Shanny of the Merck Institute, of Mrs M Sachs for the histological perparations, and Mr George N Thomas for the photomicrographs They also express their gratitude to Dr John Rhodin, head of the Lillia Babbitt Hyde Foundation Laboratories for Electron Microscopy in the Department of Anatomy, who extended the privilege of working in his excellently equipped laboratory

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Jan Wersäll, Depts of Histology & Otolaryngology
Karolinska Institutet, Stockholm
J E Hawkins, Jr, Depts of Otolaryngology & Anatomy,
New York University Medical Center, New York, N Y

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TRAINING IN OTOLARYNGOLOGY IN SCANDINAVIA[1]

Urpo Siirala
Helsinki, Finland

I. *Students*

In the Scandinavian countries the teaching of otolaryngology takes place during the later part of the undergraduate training, apparently because a basic education in medicine is a condition for understanding the particular problems of this speciality. The teachers are professors or other qualified doctors.

Table 1 shows the time that is spent on lectures, work in polyclinics and attending operations in the teaching hospitals of the different Scandinavian countries. The time reserved for teaching of otolaryngology varies considerably. In Norway and Finland it is longer than in Denmark and Sweden, evidently because the less adequate communications make it necessary for the rural physician in Norway and Finland to be able to deal with otolaryngological problems himself without the help of specialists. Therefore he needs a more thorough knowledge particularly of the practical side of E.N.T. diseases.

During the otolaryngological course it is more or less compulsory for the participating students to take part in the work in the out-patient departments. They attend otolaryngological operations and receive instruction also in audiology, bronchoesophagology, stomatology and in most university hospitals also in phoniatrics. In all of the Scandinavian countries a final examination in otolaryngology is compulsory.

The number of students in each study group is usually comparatively large. For example, in the Helsinki University Medical School each study group has 60 members. It is therefore important that the teaching and demonstrations are arranged in such a way that all of the students are able to see, hear and learn what is taught or demonstrated. In the Helsinki University E.N.T. Hospital the 60 students are divided into five groups with 12 students in each group. These five groups work in the hospital every other day—that is, three times a week, three hours at a time, for 3½ months. The five groups rotate so that one group investigates new patients in the wards, the second group is attending operations, and the third and fourth groups are working at the polyclinic seeing out-patients. The fifth group is further divided in order to visit the audiological department, to see endoscopic work and/or work at the phoniatric polyclinic. On the next day for otolaryngology the groups change places so that the first group does what the second did the

[1] Read at the conference on "Training in Otolaryngology" during the Seventh International Congress of Otolaryngology in Paris 1961.

TABLE 1 : *Undergraduate teaching in otolaryngology*

	Duration of the E N T course, weeks	Hours weekly	Hours altogether
Denmark	12	3–4	36– 48
Sweden	8	10	80
Norway	12–13	10	120–130
Finland	14	9	126

last time and so on In that way the students become acquainted with the whole work of the hospital Fig 1

If an undergraduate, after completing the course in otolaryngology, is specially interested in this field and wants to gain more experience of it, he is able to stay an additional 2 or 3 months in the hospital In Finland these students are called "amanuenses", and they get a modest salary for their work

II Specialists

The basic requirement is the degree of licentiate in medicine, which entitles to registration as an authorized physician In all of the Scandinavian countries there is a 3 year course in otolaryngology During this time the specializing physician works as an assistant surgeon in a university teaching hospital or in an otolaryngological department of some other hospital with a qualified teacher, which generally means that he must be appointed as a university instructor ("docent") in otolaryngology In addition to this the specializing physician must have preceding or supplementary training in surgery and/or in some other field of medicine In Denmark a doctor cannot become a specialist until ■ years have passed since his authorization In Finland a decision of principle has been made that the specializing doctors must pass a final examination However, this has not yet been put into practice (Table 2)

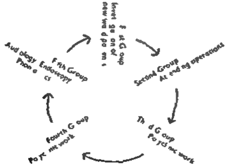

FIG 1 The rotating system of undergraduate training in the Otolaryngological Hospital of Helsinki University Teaching for three hours every other day for 3½ months

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THE RETICULAR ZONE OF THE "PLANUM SEMILUNATUM"

E Borghesan
Palermo, Italy

From the Oto laryngological Clinic (Head Prof E Borghesan), The University, Palermo

In the planum semilunatum of rabbits some epithelial zones which differ from one another are noticeable The reticular zone is made up of two types of cells, some are like those found in the vasculo epithelial zone of the limbus, others are similar to the interdental cells

By the term "planum semilunatum" is meant an area of the ampullar wall, whose epithelium is clearly differentiated and half moon shaped

According to Kolmer, the planum semilunatum extends from the ampullar wall up to the crista, in a different way, as it is thicker from the side of the semicircular canal Eckert Möbius, on the contrary, thinks that the planum semilunatum is separated from the crista by a small epithelial furrow and is made up of polymorphous cells which form special areas The more extended area consists of prismatic and clear cells, while at other points the cells are cubic and corresponding to the point of penetration of the vessels and of the nervous fibres into the ampulla, there exists a reticular zone, so called because it is composed of clear and poliedric cells, irregularly delimited by a dark substance In addition, in the ampullae, at the borders of the macula utriculi and at the sides of the macula sacculi, Iwata had previously described these cellular zones, calling them "regiones secretoriae"

The planum semilunatum, according to Saxen, consists of a "group of cells surrounding each crista acustica like a cuff" Werner, too, found that the planum semilunatum is separated from the crista and that its cells are prismatic or cubic, as recently also Bairati and Jurato have confirmed

It is evident that there is no uniformity of ideas as to the extension and the structure of the planum semilunatum, it seems, however, that different cellular groups contribute to form this ampullar region To my mind, this last consists of all the areas of the differentiated epithelial cells existing in the ampulla and on the crista ampullaris, with the exception of the sensory epithelium

The authors in the literature from Retzius to Iwata Eckert Möbius, Fieandt & Saxen to Dohlman, Bairati & Jurato, attribute to the planum semilunatum the function of secreting the ampullar endolymph

If one considers the planum semilunatum as being formed by only one type of cells, it is easy to accept this secreting activity, the same, however,

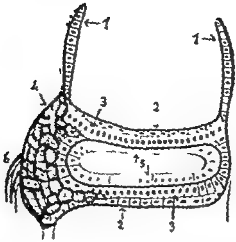

FIG 1 Schematic drawing of the planum semilunatum 1, wings, 2, pavement of the planum; 3, epithelial bands of the crista, 4, reticular zone, 5, sensory epithelium of the crista, 6, nervous fibres.

cannot be said if we regard the planum semilunatum as really composed of cells of different morphological aspect, because, in this case, it would be difficult to understand why dissimilar elements should perform the same function This idea has led me to investigate one of the least known zones of the planum semilunatum and one which differs from the others—the reticular zone

For my histological researches I made use of ampullae of rabbits; these last, fixed in osmic acid and stained with iron-haematoxylin, have been sectioned in series, following two planes, frontal and crossed, in relation to the crista

Even from a hasty microscopic observation, one can trace a schematic reconstruction of the planum semilunatum (Fig 1), showing four zones; one forms the lateral parts (wings), one lines the two faces of the crista up to

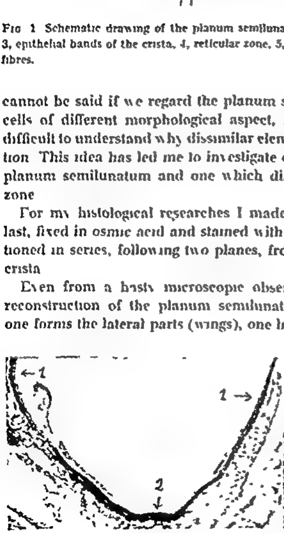

FIG 2

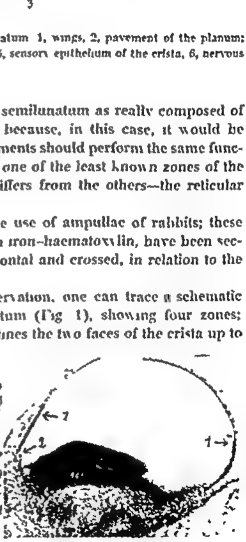

FIG 3

FIG 2 Frontal section of ampulla 1, wings 2, pavement of the planum

FIG 3 Frontal section of crista and cupula 1, wings, 2, fold of the furrow between wing and crista

Fig 4 Marginal frontal section of crista 1, reticular zone

the limit of the sensory epithelium (bands of the crista) one extends along the inferior margin of the bands of the crista (pavement), one is situated near the point of penetration of the nervous fibres (reticular zone) The design of the network of this last zone changes its aspect in different animals

A section of horizontal ampulla, close to the canalicular portion (Fig 2),

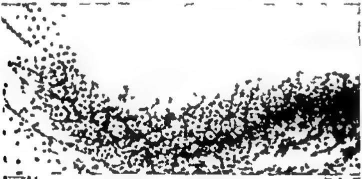

Fig 5

Fig 6

Fig 5 Marginal section of reticular zone

Fig 6 Cross-section of crista parallel to Fig 5 It is delimited by the reticular zone on both sides

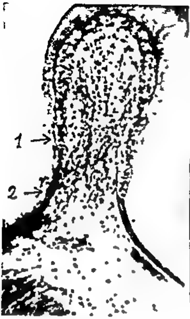

Fig 7

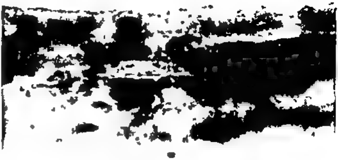

Fig 8

Fig 7 Cross section of crista 1, epithelial band comprehended between the sensory epithelium and 2, the pavement of the planum

Fig 8 Cells of the pavement of the planum semilunatum

shows that the planum semilunatum is V shaped, its lateral walls, situated like wings, are united in their inferior margin by a dark epithelial band, which forms the pavement of the planum itself In a section parallel to the preceding one and involving the crista and the cupula (Fig 3), the wings appear reduced in extension, but what is most important at this level is the presence of an epithelial fold interposed between the wing and the crista In another parallel section, almost superficial (Fig 4), in the lowest part of the crista, there is evident a clear, oval zone, which is variously intersected by dark rows different in thickness, forming an irregular network

A cross section of ampulla, near the zone reached by the nervous fibres and by the vessels, shows a reticular looking surface, extending from one side to the other of the ampulla (Fig 5) On reaching the crista, it breaks up surrounding it for a short tract (Fig 6) Further on, it reaches the epithelium of the pavement of the planum Such change of aspect does not take place simultaneously on the two sides of the base of the crista, at this point, in fact, a different type of epithelium can be observed Further on, on both sides of the crista (Fig 7), there is traceable an epithelial band comprehended between the epithelium of the pavement and the sensory one

When magnified, the wings of the planum semilunatum show a uniform stratum of prismatic cells, the structure of which is known from Fieandt & Saxén's description completed by the results of Bairati & Jurato's electron microscope studies

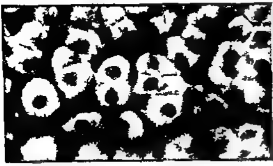

Fig 9 Structure of the reticular zone

Fig 10 Another structural aspect of the reticular zone

In the epithelial bands of the crista the cells are prismatic and differ from those of the wings because in the crista the cells show finger like processes more numerous and more intensely stained and their nuclei are dispaced towards the endolymphatic surface

The cells of the pavement are low and large their protoplasm is scarce and granular almost entirely occupied by the oval nucleus (Fig 8)

The epithelial fold of the sulcus existing between the crista and the wing is formed by globular and clear cells with spherical nuclei among which are found others with thin protoplasm and piriform or spindle shaped nuclei placed on the basal membrane or displaced towards the endolymphatic surface of the cell

The reticular zone too appears to be formed of two types of cells the more numerous (Fig 9) are poliedric or globular with protoplasm clear and with well marked borders their nuclei are clear The second type of cells is formed by elements with small and dark nuclei of variable shape Some groups or even only one of poliedric and clear cells are delimited by spaces of different widths all communicating with one another and containing an amorphous dark substance that sometimes reaches the underlying loose connective tissue where it comes into contact with the capillaries

The largest spaces contain even 3 5 cells with a small and dark nucleus of variable shape Almost often these cells are heaped and immersed in the *dark grey substance which greatly reduces the osmic acid so that as a rule* it is impossible to trace the protoplasm and very often even the nucleus itself

The characteristic aspect of the reticular zone is shown by the amorphous substance of the intercellular spaces and by the nuclei contained in them

Quite near the crista some groups of clear cells are regularly arranged around a central clear space as if this were the crossed section of a duct (Fig 10)

As we have seen in the planum semilunatum each zone is composed of epithelial cells differently arranged with the exception of those of the wings and of the bands of the crista which are almost the same

It should be emphasized that these last zones show irrelevant morphologi

manent impairment following exposure to gun noise He found that sounding a tone just before each gun blast appreciably reduced the temporary and permanent decrement in cochlear microphonic after firing No direct measure of amount of attenuation was offered by this procedure

One possible psychophysical method employed to assess intratympanic reflex attenuation involves measurement of absolute threshold in one ear in the presence and absence of loud stimulation in the cotralateral ear Shapley (1954) found that white noise in one ear raised the pure tone threshold of the contralateral ear approximately 15 db On the other hand Loeb & Riopelle (1960) found that a loud pure tone stimulus raised the threshold in the contralateral ear approximately 5 db There are at least two plausible explanations of this discrepancy Perhaps a noise is more effective for some reason in eliciting the reflex than is a pure tone or perhaps Shapley s noise contained enough low frequency energy to provide direct masking as a result of bone conduction from one ear to the other (Shapley recognized this possibility but felt that the amount of masking so obtained would account for only a fraction of the attenuation measured)

In the Loeb & Riopelle experiment previously mentioned larger values of attenuation were recorded when a loudness matching rather than a treshold shift technique was employed The authors suggested that the action of the reflex is non linear and that the mechanism once elicited attenuates loud tones more than soft ones This would account for the relatively small value of threshold shift resulting from elicitation of the reflex On the other hand this explanation would not account for Shapley s (1954) results

The purpose of this experiment was to measure threshold shift in the contralateral ear elicited by complex tones which would not produce direct masking and to compare it with the shift produced by a pure tone

PROCEDURE

If a noise is superior to a pure tone in terms of the magnitude of the elicited reflex this might be attributable to its complex spectrum or to its unsteady constantly changing character In the present study two steady sounds a sine wave and a square wave and two changing ones a narrow and a broad band noise were employed to elicit the reflex Both the sine wave and the square wave which is rich in odd harmonics were generated by a Krohn Hite oscillator set at 2200 cps The noises were generated by feeding the output of a General Radio random noise generator through a Krohn Hite active filter The nominal cut off values for the narrow band noise were 2000 and 2200 cps The lower cut off for the broad band noise was 2000 cps but no upper limit was set on the filter The Krohn Hite filter slope as cited by the manufacturer is 48 db/octave All reflex eliciting signals were presented through a PDR 8 earphone at 110 db sensation level (SL) intensity

The test stimulus was a 500 cps sinusoidal tone generated by feeding the output of a Krohn Hite oscillator through a Grason Stadler recording attenuator into a PDR 8 earphone on the contralateral side Sixteen members of the

U S Army Medical Research Laboratory served as subjects in the experiment No screening for hearing deficit was performed Each served as a subject in four experimental sessions in each of which a different one of the four reflex eliciting stimuli was employed A Latin square design was employed to insure that within the group every stimulus was employed equally often first second third and fourth in order

Experimentation was performed in an anechoic chamber with an ambient noise level of approximately 25 db Each O tracked the threshold for the 500 cps test stimulus in his right ear according to the standard Bekesy procedure After 30 sec a 110 db (SL) reflex eliciting stimulus was presented in the contralateral (left) ear After 60 sec the stimulus in the left ear was terminated and the O allowed to continue to track his treshold for 30 sec The O s instructions in all cases were to ignore the left ear stimulation and to track his threshold as consistently as possible

Averages of ascending and descending right ear limens were taken for the last two excursions of the pen before contralateral stimulation (L_1) the first two following initiation of this stimulation (L_2) comparable points 30 and 60 sec later (L_3 and L_4) for the first two excursions following termination of contralateral stimulation (L_5) and 30 sec later (L_6)

RESULTS

The median amount of loss (threshold shift) of each of the points described above is shown in Fig 1

It [illegible]
con [illegible]
for [illegible]
decreased sharply when the reflex eliciting stimulus was eliminated (L_5) After 30 sec (L_6) threshold was almost back to its pre exposure level

Because the distributions were irregular data were analyzed by the Wilcoxon *t* test (Siegel 1956) It was found that the increase in threshold when the contralateral stimulation was initiated (L_1 L_2) and the decrease after its termination (L_4–L_6) were highly significant for all reflex eliciting stimuli ($P<0$ 01)

The slight decline in loss while the eliciting stimulus was on (i e between L_2 and L_4) was statistically significant when the eliciting stimulus was a pure tone ($P<0$ 01) a square wave ($P<0$ 05) or a broad band noise ($P<0$ 01) but not when it was a narrow band noise In other words the narrow band noise was apparently more effective not only in amount of attenuation provided but also in maintaining the contraction

The statistical significances of the differences in hearing loss produced by the different eliciting sounds were computed similarly The shifts attributable to square wave stimulation did not differ significantly from those attributable to pure tone stimulation The overall shift (average at L_2 L_3 L_4) elicited by the pure tone was less than that caused by the broad band noise ($P<0$ 05) though at individual times (L_2 L_3 L_4) the differences were not significant

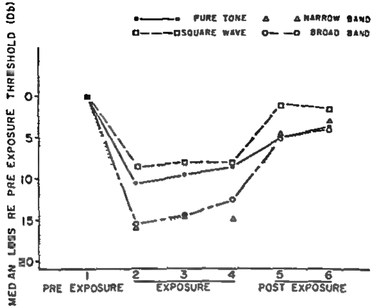

Fig 1 Amount of contralateral loss produced by each of the acoustical stimuli

At L_2 and L_3 the difference in threshold shift caused by broad and narrow band noise approached significance ($P < 0.10$) and at L_4 just before the eliciting stimulus was terminated it was significant ($P < 0.05$) The overall difference in shift attributable to narrow and broad band noise was significant ($P < 0.01$) Differences in threshold shifts between all other conditions at all times while the stimulus was present were significant at either the 0.05 or 0.01 level

In general then we might state that the narrow band noise was most effective in eliciting the reflex while the broad band noise was superior to the other conditions (pure tone and square wave) These latter two conditions did not differ significantly from one another

DISCUSSION

The findings suggest that noises are more effective in eliciting the acoustic reflex than are steady stimuli and apparently also in maintaining reflex contraction over time The fact that narrow band noise and broad band noise are similar in their effects and that pure tone and square wave stimuli had a similar influence suggests that spectrum or band width was not the principal determinant of reflex efficiency Possibly the continuously changing character of the noise stimuli was more effective in eliciting the reflex at full strength It has been suggested (Loeb & Riopelle 1960) that in a test situation like the one employed here the subject in listening may inhibit the reflex to the test stimulus This might be done more efficiently possibly for a steady stimulus like a pure tone or square wave than for a randomly changing stimulus like a broad or narrow band noise A completely satisfactory explanation cannot be given

In Galambos & Rupert's (1959) measurements of the influence of contralateral stimulation on cochlear microphonics it was found that random noise was not as effective for reflex activation as a pure tone. The authors cannot explain this discrepancy at this time.

The threshold shifts produced by the sinusoidal stimuli are somewhat larger in this experiment than the shifts caused by contralateral pure tone stimulation in Loeb & Riopelle's experiment (1960). The differences found in the two experiments are not large, but those of the present study more closely approached the values usually obtained by other methods. The attenuation apparently afforded by contralateral noise stimulation in this investigation is in better agreement with such values.

In view of the findings of this experiment it would appear that if the intratympanic reflex is deliberately elicited for protective purposes (Fletcher & Riopelle 1960), then it would be more useful to employ a narrow band noise as an eliciting agent than a sinusoidal tone.

ZUSAMMENFASSUNG

Ein früheres Experiment, die durch den akustischen Muskelreflex verursachte Schallverminderung zu beurteilen, bestand aus der Bestimmung der Steigerung der absoluten Schwelle nach gegenseitiger Reizung mit einem reinen Ton. Diese Schätzung war bedeutend kleiner als die auf andere Arten erreichten Schätzungen dieser Schallverminderung. Im vorliegenden Versuch wurde ein Ohr mit einem 110 Phon reinen Ton (Sinuswelle oder rechteckige Welle) oder mit einem 110 Phon Geräusch (schmales Frequenzband oder breites Frequenzband) gereizt, und die resultierende Veränderung der Schwelle im anderen Ohr wurde gemessen. Der reine Ton (rechteckige Welle) verursachte die kleinsten Veränderungen. Die Geräusche verursachten bedeutend grössere Schwellensteigerungen, besonders das aus schmalem Frequenzband bestehende Geräusch. Mögliche Erklärungen dieser Unterschiede wurden untersucht.

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U. S. Army Medical Research Laboratory, Fort Knox, Kentucky

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LE CONTRÔLE CENTRAL DE L'AUDITION ET SES TESTS AUDIOMÉTRIQUES

R. Maspétiol, H. Semette et Cl. Mathieu
Paris, France

Les faits audiométriques qui sont l'objet de ce travail tendent à démontrer l'existence d'une part de processus d'inhibition et de facilitation de la transmission centrale du message sonore, d'autre part d'un contrôle central de la cochlée.

Ces faits audiométriques présentent un double intérêt:

— un intérêt physiologique: ils sont la traduction audiométrique de processus neuro-physiologiques mis en évidence par différents auteurs;

— un intérêt clinique: d'une part ils constituent des tests audiométriques permettant d'aborder sous un angle nouveau le problème clinique des surdités centrales, d'autre part ils amènent à reviser certaines notions pathogéniques concernant les surdités cochléaires avec recrutement.

LES CONSTATATIONS AUDIOMÉTRIQUES

Étude du seuil différentiel d'intensité (S.D.I.) en présence d'un son controlatéral

Chocholle (1–2) en étudiant les seuils différentiels d'intensité en présence d'un son controlatéral continu de faible intensité a fait les deux constatations suivantes:

a) le seuil différentiel d'intensité augmente d'amplitude en présence d'un son controlatéral invariable et de *même fréquence*. Il s'agit donc d'un *effet inhibiteur* puisque l'augmentation du S.D.I. traduit une diminution de la sensibilité différentielle.

b) Le seuil différentiel d'intensité diminue d'amplitude en présence d'un son controlatéral invariable et de *fréquence différente*. Dans ce cas il s'agit d'un *effet de facilitation* puisque la diminution du S.D.I. traduit une augmentation de la sensibilité différentielle.

Étude de la fatigue auditive en présence d'un son controlatéral de faible intensité

Dans un travail récent (3) nous avons montré que si on recherche la fatigue auditive post-stimulatoire selon la technique de Peyser avec en même temps sur l'oreille controlatérale un son de faible intensité (par exemple bruit blanc ou 250 Hz à 30 dB) on constate que la fatigue auditive est diminuée par rapport à celle observée après une épreuve de Peyser simple, c'est-à-dire sans son controlatéral. Cette diminution de la fatigue auditive porte et sur la perte en décibels et sur le temps de récupération. La diminu-

tion de la fatigue est constante quelle que soit la nature du son controlatéral (bruits blancs ou sons purs de fréquence soit identique soit différente de la fréquence utilisée dans l'épreuve de Peyser).

Dans ce même ordre d'idées Brunetti (4) a signalé dernièrement l'existence de modifications de l'adaptation auditive d'origine centrale par interférences sensorielles et notamment par stimulus sonore controlatéral.

Sans vouloir aborder dès maintenant l'aspect physiologique de ces faits audiométriques, il convient cependant de remarquer que l'action d'un son controlatéral de faible intensité (à 10-20 dB au dessus du seuil) et sur le seuil différentiel d'intensité et sur la fatigue auditive ne peut pas être une action directe sur l'oreille testée; il ne peut s'agir que d'une action d'origine centrale.

Si ces effets d'inhibition et de facilitation d'un son controlatéral observés chez les sujets normaux impliquent bien une origine centrale, par contre, dans le domaine clinique l'absence de ces mêmes effets d'un son controlatéral et sur le seuil différentiel d'intensité et sur la fatigue auditive doit amener à conclure à une lésion du système nerveux central. C'est là une notion qu'il convient de mettre en évidence avant d'aborder l'intérêt clinique de ces faits audiométriques.

INTÉRÊTS CLINIQUES

Surdités centrales et corticales

Les modifications du S.D.I. et de la fatigue auditive en présence d'un son controlatéral constituent deux tests audiométriques qui semblent être valables pour le diagnostic des surdités centrales (5).

a) *Le test non verbal d'intégration biauriculaire* (T.I.B.) est basé sur la recherche des effets de facilitation et d'inhibition du S.D.I. en présence d'un son controlatéral. Il s'agit bien là d'un test d'intégration biauriculaire puisque les deux oreilles perçoivent un stimulus sonore; il est non verbal puisqu'afin d'éliminer les troubles du langage on utilise non pas la parole mais des sons purs.

La recherche de ce test est pratiquée de la manière suivante: on recherche d'emblée le S.D.I. (fréquence 1000 + 40 dB) avec sur l'oreille opposée la fréquence 250 + 30 dB. Sans changer le S.D.I. ainsi obtenu, on remplace sur l'oreille opposée la fréquence 250 par la fréquence 1000 + 30 dB. Normalement le son de l'oreille testée cesse d'être modulé, il devient continu. Il faut augmenter le S.D.I. pour que le sujet perçoive à nouveau des modulations.

En cas de trouble de l'intégration biauriculaire, le fait de passer sur l'oreille controlatérale de la fréquence 250 à la fréquence 1000 n'entraîne pas de modification du son testé; il est toujours perçu modulé. Il n'y a donc ni effet de facilitation (fréquence 250) ni effet d'inhibition (fréquence 1000).

Dans l'étude des troubles auditifs d'origine corticale et centrale ce test s'est montré particulièrement valable (6).

Dans les lesions corticales ce test etait perturbe dans la presque totalite des cas de lesions temporales (13 fois sur 14) Parfois il a meme ete possible de suspecter une lesion temporale malgre un examen neurologique negatif diagnostic qui a eté confirme ulterieurement par des examens complementaires arteriographie ventriculographie EEG

Dans les lésions centrales avec surdité ou notre experience est reduite — elle ne porte que sur deux cas — le test d integration biauriculaire etait perturbe Dans les lesions du tronc cerebral sans surdite ce test a ete trouve perturbe dans la moitié des cas environ

b) *Le test d inhibition central de la fatigue auditive (T I A)* Ce test est base sur la recherche de la diminution de la fatigue auditive en presence d un bruit blanc ou de la frequence 2o0 +30 dB sur l oreille opposee

La non diminution de la fatigue auditive en presence d un son controlateral est pathologique

Bien que notre experience de ce test soit plus recente il semble possible de dire que ce test a la meme valeur et la meme signification que le test precedent En effet les réponses donnees par les deux tests ont toujours ete concordantes

Dans le domaine des lesions corticales il est un autre test que nous ne ferons que mentionner car il sort du cadre de cette étude c est *le temps de reaction auditive* (5) Ce test a une valeur topographique differente Il semble etre perturbe dans les lesions temporales superficielles tandis que les tests d integration biauriculaire et d inhibition centrale de la fatigue auditive semblent correspondre a des lesions plus profondes et traduire — nous le verrons — un dysfonctionnement dans les interconnexions cortex–substance reticulee

Recrutement et controle central de la cochlee

Si la valeur topographique du recrutement n est pas discutable il s agit bien la d un signe caracteristique d une lesion cochleaire par contre certains faits audiometriques amenent a penser que le mecanisme de production de cette lesion cochleaire cause de recrutement est le plus souvent d origine centrale secondaire a des perturbations d un systeme regulateur central

Cette conception centrale du mecanisme de production du recrutement est basee sur les faits suivants

a) Le test d integration biauriculaire est perturbe En effet le seuil differentiel d intensite reste inchange quel que soit le son controlateral

On pourrait penser que ces troubles de l integration biauriculaire peuvent etre la consequence du recrutement lui meme En effet l abaissement marque du S D I peut rendre difficile voire meme impossible la recherche de l effet de facilitation Il ne resterait que l effet d inhibition Mais il convient de remarquer que c est l effet d inhibition qui est le plus actif de plus ces troubles d integration sont souvent bilateraux portant ainsi sur l oreille opposee qui ne presente pas de recrutement

On pourrait incriminer egalement une technique d examen defectueuse

En effet, sur bien des audiomètres l'écart des seuils différentiels d'intensité est très étroit entre 0,1 et 0,6, rendant ainsi bien difficile la mise en évidence d'une différence des seuils différentiels en cas de recrutement, mais des examens répétés avec un audiomètre approprié et chez des sujets donnant des réponses très précises ne peuvent laisser aucun doute sur la réalité de ces faits.

b) Le test du contrôle central de la fatigue auditive est également perturbé: un son controlatéral de faible intensité ne diminue pas la fatigue auditive. Ce test ne peut prêter à confusion.

Les réponses pathologiques de ces deux tests amènent à conclure que dans le recrutement il existe une participation centrale. Que cette participation centrale soit secondaire à la lésion périphérique ne peut guère être envisagé: cette hypothèse serait contraire à ce que l'on sait sur le système central. Il apparaît plus rationnel de considérer ces troubles centraux comme constituant le phénomène primitif.

A ces arguments audiologiques il convient d'ajouter les deux faits suivants:

a) Du point de vue clinique, Thibault et Greiner (7–8) ont publié des observations de surdité avec recrutement dans des lésions du tronc cérébral.

b) Du point de vue vestibulaire, Montandon (9) a montré par l'épreuve giratoire liminaire que dans le vertige de Ménière qui s'accompagne souvent de surdité et alors toujours associé à un recrutement, il existe une note centrale. De notre côté avec Robert (10) nous avons pu confirmer par cupulométrie, du moins dans la plupart des cas, les constatations faites initialement par Montandon.

Cependant, à côté des *recrutements secondaires à un processus central* et qui sont les plus fréquents, il existe des *recrutements purement périphériques*, c'est-à-dire sans altérations de ces tests audiométriques qui interrogent des processus centraux. Ces recrutements périphériques semblent être le témoin d'un oedème collatéral secondaire à une lésion de voisinage. C'est ainsi que nous avons observé ces « recrutements périphériques »:

— dans des catarrhes tubo-tympaniques avec participation cochléaire, fait constaté spécialement chez les allergiques;

— dans les traumatismes cochléaires secondaires à une mobilisation de l'étrier;

— dans l'hypertension intracranienne. Dans ce cas il ne s'agit d'ailleurs le plus souvent que d'un recrutement partiel portant sur les fréquences aiguës.

INTÉRÊT PHYSIOLOGIQUE

Les constatations audiométriques et cliniques qui viennent d'être exposées permettent de dégager les faits suivants:

1° L'action observée chez les sujets normaux d'un son controlatéral de faible intensité (10 à 20 dB au-dessus du seuil) et sur le seuil différentiel d'intensité et sur la fatigue auditive ne peut pas être une *action directe sur*

l oreille testee ni sur la cochlee ni sur les muscles ossiculaires Il ne peut s agir que d une *action d origine centrale* et il semble qu on puisse faire intervenir la formation reticulee dont on connait bien du point de vue neuro physiologique les effets d inhibition et de facilitation

2° Sur le plan pathologique les constatations audiometriques et cliniques semblent bien montrer l existence de deux faits distincts

a) c est tout d abord l existence d un controle de la transmission centrale jusqu a un niveau cortical du message auditif Ce controle de la transmission se traduit sur le plan pathologique par les altérations des tests audiometriques (T I B – T I F) d une part dans les lesions corticales d autre part dans les lesions centrales

b) C est enfin l existence d un controle central de l organe peripherique de la cochlee qui se traduit sur le plan pathologique par des alterations de ces deux tests dans certaines surdites avec recrutement

Cette doube action centrale et sur la transmission du message auditif le long des voies centrales et sur l organe peripherique apparait etre bien etablie du point de vue neuro physiologique Elle semble devoir etre attribuee a la substance reticulee dont le role fondamental a ete mis en evidence ces dernieres annees grace notamment aux travaux de Magoun Hernandez Leon Bonvallet Dell Fessard Jasper

La substance reticulee constitue on le sait un systeme non specifique construit en parallele avec les voies motrices et sensorielles classiques et etendue le long de la plus grande partie du tronc cerebral L influence de cette formation s etend dans de nombreuses directions comme les rayons d une roue qui partent du moyeu pour aller s encastrer dans la jante selon la comparaison de Magoun (11) Les effets fonctionnels de cette formation retentissent « sur les autres fonctions du systeme nerveux central soit pour augmenter ou diminuer leurs niveaux d activite soit pour les relier ou les integrer » (Magoun) De ces multiples effets fonctionnels nous retiendrons

a) pour expliquer les alterations audiometriques dans les lesions corticales et centrales le controle réticulaire de la transmission centrale des messages afferents et les inter reactions cortex substance reticulee

b) pour expliquer le controle central de la cochlee les effets reticulaires centrifuges agissant a la peripherie sur l organe recepteur et les effets reticulo hypothalamiques

Controle reticulaire de la transmission centrale des messages auditifs et inter reactions cortex substance reticulee

a) *Controle reticulaire de la transmission centrale* Ce fait bien etabli du point de vue neuro physiologique semble bien expliquer les alterations des tests audiometriques dans les lesions centrales

Ce sont les processus d inhibition qui ont surtout ete mis en evidence L inhibition centrale presente des fonctions differentes

Nous n envisagerons pas la fonction de coordination des differents centres

sensoriels (Fessard (12)). Signalons seulement qu'il a été démontré chez le chat un blocage au niveau des noyaux cochléaires lors d'état d'attention visuelle (Hernandez Peon (13)); chez l'homme au cours d'intervention neuro-chirurgicale, Dechaume (14) a mis en évidence des faits analogues pour la vision.

A côté de cette fonction coordinatrice des différents centres sensoriels, la substance réticulée a une action sur les neurones d'un même centre. C'est cette action que nous retiendrons car elle explique les faits audiométriques observés et chez les sujets normaux, et chez les sujets atteints d'affection centrale.

Pour Fessard (12) il existe un dispositif des voies récurrentes réalisant un « feed back » negatif appliqué aux neurones d'un même centre. Ce dispositif est à la base de la fonction frénatrice à la fois protectrice et stabilisatrice de l'inhibition.

C'est par un phénomène d'inhibition que Galambos explique le rétrécissement remarquable de la gamme des fréquences à laquelle peut répondre chaque neurone des noyaux cochléaires lorsqu'on applique à l'oreille un autre son.

Selon l'intensité de la stimulation électrique de la zone de décussation du faisceau olivo-cochléaire, Ruben et Sikula ont constaté l'abolition de la réponse auditive, soit au niveau des aires auditives, soit au niveau du corps genouillé, soit au niveau du nerf auditif.

Dans le domaine des afférences somatiques, Hernandez Peon (16) a constaté des effets réticulaires inhibiteurs au niveau des noyaux du trijumeau.

Au niveau du bulbe olfactif, Kerr et Hagbarth (17) ont constaté des effets dépressifs par l'intermédiaire de fibres centrifuges dans la commissure antérieure.

Des expériences ont montré que la substance réticulée mésencéphalique pouvait, lorsqu'elle est stimulée, bloquer la transmission d'un message afférent à un niveau cortical (14).

Les effets de facilitation de la substance réticulée semblent n'avoir pas été aussi nettement mis en évidence du point de vue neurophysiologique. Il convient d'ailleurs de signaler que dans le test d'intégration biauriculaire les effets d'inhibition *paraissent être plus importants que les effets de facilitation*. Cependant pour Hernandez Peon (18) il existe un contrôle centrifuge qui s'exerce à tous les niveaux des voies sensorielles qui partagent avec le cortex un rôle non seulement d'inhibition mais de facilitation sur les effets des stimulations sensorielles. C'est ainsi que la destruction des formations mésencéphaliques tegmentales accroît l'activité afférente évoquée du noyau cochléaire et du bulbe olfactif.

Desmedt a pu obtenir également, à côté des effets d'inhibition, des effets de facilitation des influx sensoriels auditifs au niveau des voies centrales.

b) Inter-réactions cortex-substance réticulée. L'existence de ces inter-réactions semble expliquer les altérations des tests audiométriques dans les lésions du cortex temporal.

Du point de vue neuro physiologique ces inter reactions sont bien admises On a pu mettre en évidence des projections reticulaires centrifuges (Magoun (11)) Une serie de travaux entrepris par Jasper (19) et par Bremer (20) a montre qu un certain nombre d aires corticales notamment temporales etaient reliees a la formation reticulaire du tronc cérébral

L efficacite des effets corticifuges sur les transmissions de l excitation a l interieur des formations reticulaires a éte demontree par Adey Segundo et Livingston (21)

Pour Hernandez Peon le controle centrifuge exerce a tous les niveaux des voies sensorielles est realise non seulement par les fibres centrifuges mais aussi par le cortex Une regulation corticale directe s effectue vers la substance reticulée (18)

Ainsi du point de vue neurophysiologique *le controle reticulaire de la transmission centrale des messages afferents et les inter reactions cortex-substance reticulee semblent etre des faits bien etablis*

L action d un son controlateral et sur le seuil differentiel d intensite et sur la fatigue auditive et les alterations de ces tests decelees dans les lesions centrales et corticales paraissent bien devoir etre rattachees a ces processus neurophysiologiques

Contrôle central de la cochlee

L hypothese d un controle central de la cochlee hypothese suggeree par les alterations des tests audiometriques dans certaines surdites avec recrutement semble etre confirmee par certains faits neurophysiologiques Il convient d envisager successivement les effets réticulaires centrifuges et les effets reticulaires sur les fonctions vegetatives et les structures hypothalamiques

a) Effets reticulaires centrifuges agissant sur l organe recepteur Au point de vue anatomique on a decrit des voies auditives efférentes et notamment le *faisceau olivo cochleaire de Rasmussen* Le role de ce faisceau semblait avoir ete demontre par Galambos en 1956 (22) la stimulation du tronc cerébral au voisinage de la decussation de la voie olivo cochleaire produit une inhibition des potentiels cochleaires Mais en 1958 Galambos est revenu sur les resultats de cette premiere experience au cours du Congres International d Audiologie (Padoue)

Cependant pour Hernandes (23) le faisceau olivo cochleaire semble bien representer la partie terminale d un système efferent s étendant depuis le cortex jusqu a la cochlee

Pour Gisselson (24) la stimulation de ce faisceau olivo cochleaire augmente l amplitude des potentiels microphoniques et cette augmentation serait en relation avec la liberation d acetylcholine dans la cochlee

Des faits analogues ont ete mis en evidence pour la vision Granit (25) a decouvert des effets reticulaires centrifuges qui s exercent sur l activite retinienne et qui sont a la fois de nature facilitatrice et inhibitrice

b) Effets reticulaires sur les fonctions vegetatives et les structures hypothala

niques Le fonctionnement normal de l appareil cochleo vestibulaire necessite une regulation constante pour regler la tension et la composition des liquides endolabyrinthiques Cette regulation s effectue par l intermediaire du systeme vago sympathique sous le controle des structures hypothalamiques Du point de vue neurophysiologique les relations formation reticulee hypothalamus sont bien etablies (Magoun (1))

Ainsi du point de vue neurophysiologique l hypothese d un systeme regulateur central de la cochlee semble bien etre confirmee Cette regulation centrale peut etre directe par des effets reticulaires centrifuges ou indirecte par l intermédiaire des effects reticulo hypothalamiques ceux ci agissant sur les activites vegetatives et secondairement sur les liquides endolabyrinthiques

CONCLUSIONS

Il est habituel de considerer la transmission des messages auditifs comme un processus dependant uniquement des excitations sensorielles peripheriques et se faisant le long du systeme nerveux central par des voies specifiques d une maniere toujours identique selon une activite du type tout ou rien Cette conception a amené a diviser en des compartiments bien tranches et autonomes les differents segments des voies auditives cochlee nerf auditif voies centrales cortex

Les faits que nous venons d exposer tant sur le plan clinique que neurophysiologique tendent a demontrer que le systeme auditif forme un tout

Les differents segments des voies auditives ne peuvent etre que tres artificiellement fragmentees puisque les differents segments agissent l un sur l autre En effet le fonctionnement de la cochlee semble bien etre sous la dependance des centres regulateurs centraux De plus la transmission centrale des messages afferents peut etre modifiee par les effets inhibiteurs ou facilitateurs de la reticulee Enfin une regulation corticale s effectue sur la substance reticulee

Si l examen mono auriculaire est une necessite clinique il apporte un élément d imperfection le seuil differentiel d intensite depend des perceptions de l oreille opposee la fatigue auditive diminue en presence d un son controlateral

En dehors de ces considerations generales l intérêt de ces faits audiometriques qui traduisent du point de vue physiologique un controle central de l audition est d ordre clinique ils constituent des tests audiométriques qui permettent d aborder sous un angle nouveau les troubles auditifs centraux et corticaux

RÉSUMÉ

1° Certains faits audiométriques — action d un son controlatéral de faible intensité sur le seuil différentiel d intensité (Chocholle) et sur la fatigue auditive — tendent à démontrer l existence d une part de processus d inhibition et de facilitation de la transmission centrale du message auditif d autre part d un contrôle central de la

cochlée. Du fait de la faible intensité du son controlatéral, il ne peut s'agir d'une action directe sur l'oreille testée, mais d'une action centrale.

2° Du point de vue clinique, ces constatations audiométriques sont à la base de deux tests audiométriques qui semblent être valables pour le diagnostic des surdités corticales et centrales. De plus, les altérations de ces tests dans les surdités avec recrutement amènent à reconsidérer certaines notions pathogéniques. Si le recrutement traduit bien une lésion cochléaire, cette lésion cochléaire est le plus souvent secondaire à des perturbations d'un système régulateur central.

3° Du point de vue neuro-physiologique, ces faits audiométriques sont la traduction clinique de processus neuro-physiologiques bien établis actuellement:

- c'est le contrôle réticulaire de la transmission centrale de messages auditifs et les inter-réactions cortex–substance réticulée;
- ce sont les effects réticulaires centrifuges agissant sur l'organe récepteur et les effets réticulo-hypothalamiques.

SUMMARY

(1) In this paper we have studied the action of a contralateral sound of feeble intensity of the differential threshold of intensity (Chocholle) and on the auditive fatigue. This study tends to show the existence, on the one hand, of inhibition and facilitation processes in the central transmission of the auditive message and, on the other hand, of a central control of the cochlea.

(2) From a clinical point of view, these facts we noticed are at the bottom of two audiometric tests: the vocal test of biauricular integration and the central control test of auditive fatigue. These tests seem to bring valuable information as to the diagnosis of cortical central deafnesses. Moreover, owing to the fact that these tests are modified in recruitment deafnesses, we have to consider again the concept of recruitment. This recruitment is indeed the proof of a cochlear lesion, which is more often secondary to a defective central regulation system.

(3) From a neurosurgical point of view these audiometric facts are the clinical expression of well determined neuro-physiological processes, viz. the reticular control of central transmission of auditive messages and the inter-reactions of cortex and reticulated substance, the *centrifugal reticulated effects acting* on the receptor organ and the reticulo-hypothalamic effects.

ZUSAMMENFASSUNG

1) Gewisse audiometrische Tatsachen zielen darauf hin, einesteils die Abschwächung und Vereinfachung der zerebralen Übertragung von Gehörtem und andererseits die zerebrale Kontrolle der Schnecke zu beweisen. Es ist dies das Studium der kleinsten Lautstärken (Chocholle) und ist andererseits das Studium der Hörermüdung in Gegenwart eines auf die Gegenseite einwirkenden Tones von schwacher Eindringlichkeit. Die Tatsache der schwachen Eindringlichkeit zeigt, es kann sich nicht um eine direkte Aktion auf das getestete Ohr handeln, sondern um eine zerebrale Aktion.

2) Vom klinischen Standpunkt aus sind diese audiometrischen Befunde die Basis von zwei audiometrischen Testen, welche gültig sind für die Diagnostik der kortikalen oder zerebralen Schwerhörigkeit. Andererseits führen die Schwankungen der Teste der Schwerhörigkeit mit Recruitement dazu, gewisse Begriffe erneut zu betrachten. Falls sich dieses Recruitement in einer Verletzung der Schnecke äussert, so

ist diese Verletzung der Schnecke sekundär im Verhaltnis zu den Störungen des zerebralen Verteiler-Systems

3) Vom neuro physiologischen Standpunkt aus sind diese audiometrischen Tatsachen die klinische Übersetzung des neuro physiologischen Verfahrens, welches klar hervorhebt, d h die netzförmige Kontrolle der zerebralen Übertragung des Gehorten und die Reaktionen des netzförmigen Substanz auf die Hirnrinde und umgekehrt, *und die netzformig zentrifugalen und die reticulohypothalamischen* Effekte, welche auf die Hororgane einwirken

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Hôpital Bichat, 170 Bd Ney, Paris 18ᵉ

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CLINICAL APPLICATION OF OPTOKINETIC NYSTAGMUS

Optokinetic Pattern Test

JUN ICHI SUZUKI and ATSUSHI KOMATSUZAKI
Tokyo, Japan

From the Department of Otorhinolaryngology (Head Prof Ichiro Kirikae, M D), Faculty of Medicine, University of Tokyo

Optokinetic nystagmus was provoked by constant acceleration followed by constant deceleration of an electrically controlled rotating drum Nystagmus thus induced was recorded on a chart fed at the speed of 0 1 cm sec⁻¹ A two channel electronystagmograph was used with time constants of 6 sec and 0 015 sec, in order to approximate the former to eye deviation and the latter to eye speed Eye speed of the slow phase of induced nystagmus in normals increases and decreases in close approximation to the angular speed of the drum, giving a cone like appearance as illustrated The authors denominated the patterns thus obtained optokinetic pattern (OKP), and the procedure, OKP test' OKP was modified by a weak spontaneous vestibular nystagmus in proportion to its degree When optokinetic stimulation was applied to spontaneous nystagmus of ocular or central origin, OKP appeared to show characteristic patterns according to causative lesions An analysis of these patterns, therefore, is expected to contribute to differentiation and identification of spontaneous nystagmus

Examination of spontaneous nystagmus, in the authors opinion is most important in clinical examinations of vertigo or loss of balance cases Electronystagmographic or photoelectronystagmographic analysis of nystagmus has come to be a routine clinical test and is epoch making in the study of nystagmus Electronystagmography is certain to become in the none too distant future one of the most important clinical tests in the same way as electroencephalography and electrocardiography are

Nystagmic reaction to optokinetic stimulation is utilized as objective method in the examination of highly disturbed vision and infantile visual acuity It is also useful for the differentiation of ocular nystagmus from other types estimation of alcohol or other drugs which influence optokinetic nystagmus diagnosis of central neural disturbances such as brain tumors situated on the temporal lobe, etc Thus although optokinetic nystagmus is known to be useful in clinical examinations it is at present, far from being widely utilized and is probably limited to an academic interest

The authors present a new type of clinical test utilizing optokinetic nystagmus optokinetic pattern test (OKP test), which should greatly aid in diagnosis of central neural disorders including vestibular disturbances

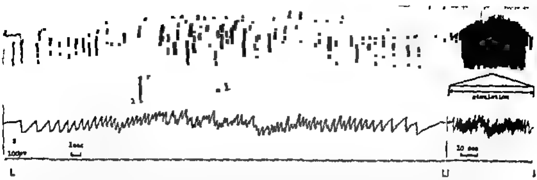

Fig. 1. Optokinetic nystagmic reaction against clockwise rotation of the drum. The upper curve was recorded with a time constant of 0.015 sec (eye speed), the lower, time constant being 6 sec (eye deviation). Feeding speed from I to II in 0.5 cm/sec, from II to III in 0.1 cm/sec. Clockwise optokinetic pattern is thus obtained (l-OKP). *n*, direction of normal optokinetic nystagmus.

METHOD

Optokinetic stimuli were given by an electrically controlled rotating drum, 1.8 m in diameter, 1.2 m in height, with a vertical rotatory axis and twelve black vertical stripes 3 cm wide interiorly. The drum can be rotated with a required constant angular velocity from 0° to 180° sec^{-1}. The angular speed of the drum is changed continuously with an angular acceleration of 4° sec^{-2}. Nystagmic movements induced by optokinetic stimulation were registered by a direct writing two channel recorder electronystagmograph (ENG) manufactured by Rion Co. of Tokyo. Paper was fed at 0.1 cm sec^{-1}. Time constant was 6 sec and 0.015 sec in order to approximate the former to eye deviation, the latter to eye speed. The test subject sits at the centre of the drum and is told to follow with his eyes the moving stripes running horizontally across his visual field.

The formula of rotation used in OKP tests is as follows. Rotation of the drum is accelerated from 0° to 100° sec^{-1} within a time period of 25 sec and immediately decelerated to zero with the identical but negative acceleration. *This is followed by another rotation to the opposite direction.* Recordings of optokinetic nystagmus thus induced give characteristic patterns as illustrated in the figures.

RESULTS

Optokinetic Patterns (OKP)

In normals, during the slow phase of nystagmus, the eyes move with a close approximation to the angular velocity of the drum. It becomes difficult, however, for the eyes to keep up with the drum as it gains in speed. Normal patterns thus obtained are shown in Fig. 1. As illustrated, the recording of eye speed, especially, gives characteristic patterns. As read in other reports, optokinetic fusion limits show a large individual variation, but no remarkable directional differences between rotation to the right and to the left. Directional

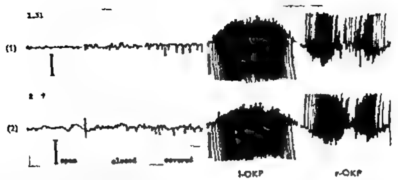

Fig 2 Recovery course of compensation after acute right labyrinthine disturbance (Eye speed recording only) (1) Recording of spontaneous nystagmus with the eyes open closed and covered respectively and OKP recorded 3 days after onset of the disease (2) Recordings 10 days after onset

difference if any must be caused by directional preponderance of optokinetic reaction Therefore it is necessary to compare patterns obtained through a set of both rotations

OKP of peripheral labyrinthine nystagmus

Peripheral labyrinths have tonic influences upon extra ocular muscles Spontaneous vestibular nystagmus influences optokinetic fusion limit i e elevates the fusion limit of optokinetic nystagmus provoked towards the side of the direction of spontaneous nystagmus while it lowers that towards the opposite side Thus OKP of spontaneous vestibular nystagmus as illustrated in Fig 2 is asymmetrical in proportion to the degree of spontaneous nystagmus this being convenient in following the course of recovery after acute peripheral labyrinthine disturbances It is also to be noted that OKP appears asymmetrical even when spontaneous nystagmus is so weak that it does not appear until the eyes are closed or covered OKP is therefore useful in detecting both spontaneous vestibular nystagmus and its degree In subjects whose fusion limit is high or whose vestibular spontaneous nystagmus is weak it is sometimes necessary to elevate the maximum speed of the drum up to 180° sec $^{-1}$ or more

OKP of spontaneous ocular nystagmus

In ocular nystagmus the mechanisms which enable the patient to gaze at a point or to follow moving objects are disturbed but the disturbance in each case does not appear to be the same either in degree or in nature The mode of reaction of spontaneous ocular nystagmus against optokinetic stimulation therefore is not so simple as that of spontaneous vestibular nystagmus Suzuki reporting in a previous paper an electronystagmographic study of ocular nystagmus reaction to optokinetic stimulation stated that it is very different from that of normal subjects and at the same time it varies from case to case Also it is not only useful in identification of ocular nystagmus

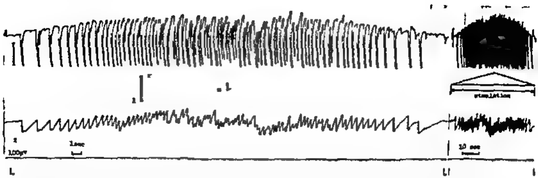

Fig 1 Optokinetic nystagmic reaction against clockwise rotation of the drum The upper curve was recorded with a time constant of 0 015 sec (eye speed) the lower, time constant being 6 sec (eye deviation) Feeding speed from L to L in 0 5 cm/sec from I to I in 0 1 cm/sec Clockwise optokinetic pattern is thus obtained (I OKP) n direction of normal optokinetic nystagmus

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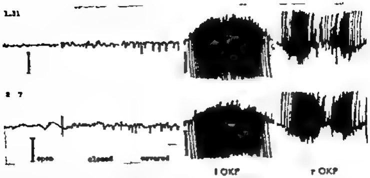

Fig. 2. Recovery course of compensation after acute right labyrinthine disturbance. (Eye speed recording only.) (1) Recording of spontaneous nystagmus with the eyes open, closed and covered respectively, and OKP recorded 3 days after onset of the disease. (2) Recordings 10 days after onset.

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OKP of spontaneous ocular nystagmus

In ocular nystagmus, the mechanisms which enable the patient to gaze at a point or to follow moving objects are disturbed, but the disturbance in each case does not appear to be the same either in degree or in nature. The mode of reaction of spontaneous ocular nystagmus against optokinetic stimulation, therefore, is not so simple as that of spontaneous vestibular nystagmus. Suzuki, reporting in a previous paper an electronystagmographic study of ocular nystagmus reaction to optokinetic stimulation, stated that it is very different from that of normal subjects, and, at the same time, it varies from case to case. Also, it is not only useful in identification of ocular nystagmus

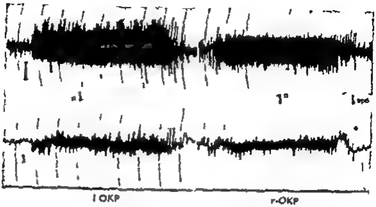


Fig 3 Reversed type of optokinetic nystagmic reaction Induced optokinetic nystagmus is 'atypical' with both directions of stimulation Changing of angular speed of drum has no influence on eye speed of induced nystagmus

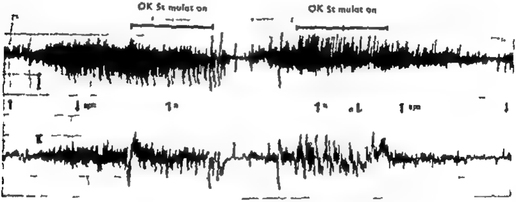


Fig 4 OKP of alternately direction changing type of congenital nystagmus Optokinetic nystagmic reaction is hardly perceptibel

but, possibly, in classification of ocular nystagmus itself The OKP of ocular *nystagmus, accordingly, is entirely different from that of normals* and that of spontaneous vestibular nystagmus and shows marked variations OKP recorded in two cases of ocular nystagmus are illustrated in Figs 3 and 4

OKP of spontaneous nystagmus of central origin

There are many pathological conditions in the central nervous system provoking spontaneous nystagmus possibly characteristic of the site of lesion Such lesions may affect the mechanisms of reaction against optokinetic stimulation, thus bringing about abnormal optokinetic reactions and modified OKP in consequence The authors anticipate *making use of* OKP for differential diagnosis of diseases in the central nervous system, because it is reasonable to expect different types of optokinetic reaction or modified OKP according to the site of lesion

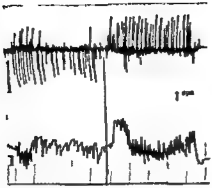


FIG 5 OKP of a spontaneous nystagmus case with diagonal nystagmus (coarse vertical and fine horizontal components) suspectedly caused by basilar artery insufficiency Though direction of induced nystagmus is typical, eye speed of nystagmus does not change when drum is accelerated or decelerated Nystagmic beats are rare in frequency

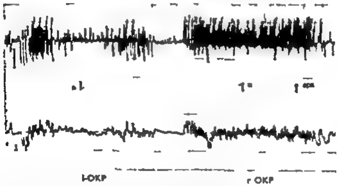


FIG 6 OKP of the fourth ventricle tumour with spontaneous nystagmus to the right The eyes are found to follow stripes in the first several seconds of stimulation or during low speed rotation Spontaneous nystagmus is markedly augmented in r OKP

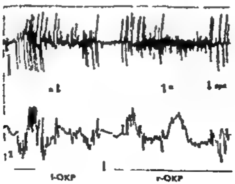
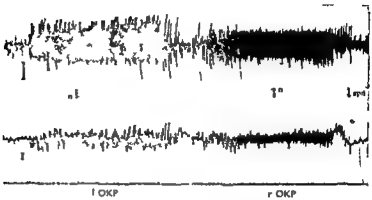


FIG 7 OKP of spontaneous nystagmus of unknown central origin Compare the difference between this and others shown in preceding figures



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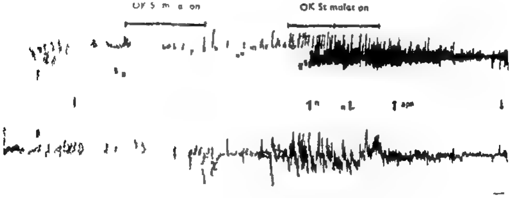

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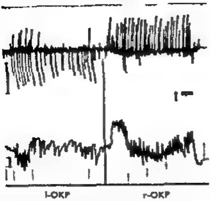

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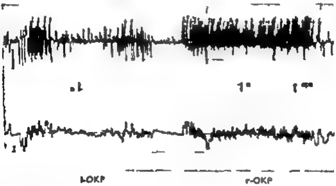

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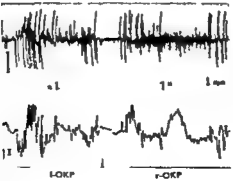

Fig 7 OKP of spontaneous nystagmus of unknown central origin Compare the difference between this and others shown in preceding figures

COMMENTS

Nystagmic curves recorded by electronystagmography are worth while studying and serve to give a great deal of important information. Nystagmus induced in normals by optokinetic stimulation is a typical jerky type which, being frequent and large in amplitude, is favourable for both recording and analysing electronystagmographically.

It has been said that the greatest drawback of the test for computing optokinetic reaction lies in the willingness or otherwise of the test subject to visually fix upon and follow the moving stripes. However, this has been proved to be no serious problem, provided patients are fully cooperative when undergoing the examination.

In this study an effort was made to observe the reaction as a whole pattern before going too deep into a detailed analysis of each nystagmic curve. Compact recording of ocular movements obtained by slowing the feeding speed of the chart makes it a simple matter to compare recordings obtained and informs us of much which would otherwise be lacking in analysis of normal speed recording. OKP as introduced and interpreted in this paper will possibly serve for classification of spontaneous nystagmus into small groups and consequently for differential diagnosis of causative lesions. The fact that OKP is readily modified by weak spontaneous vestibular nystagmus in proportion to its degree is of important clinical significance in examination.

ZUSAMMENFASSUNG

Optokinetischer Nystagmus wurde durch die konstante positive und die sofort darauf folgende negative Winkelbeschleunigung des elektromotorischen Drehzylinders hervorgerufen und elektronystagmographisch mit Zeitkonstanten von 6 und 0,015 Sek. auf dem mit 0,1 cm/Sek. gefütterte Papier registriert. Ein Zweikanal elektronystagmograph wurde verwendet, indem mit der Zeitkonstante von 6 Sek. die ungefähre Augendeviation und von 0,015 die Geschwindigkeit der Deviation zu erzielen erwartet wurde. Die Geschwindigkeit der langsamen Phase des Nystagmus beim normalen Menschen nimmt in annähernder Entsprechung der Winkelgeschwindigkeit des Drehzylinders zunächst zu und dann ab. Die so gewonnene Registrierungsfigur zeigte eine kuppelähnliche Form. Die registrierte Figur soll 'optokinetic pattern (OKP)' und das Verfahren 'optokinetic pattern test (OKP test)' bezeichnet werden. Die Untersuchung ergab, dass sich OKP der Intensität des vestibulären Spontannystagmus entsprechend quantitativ verändert, wie in Abb. 2 zu sehen ist. Bei der Anwendung des Verfahren auf Zentral- oder Okularnystagmus zeigte OKP den ursächlichen Läsionen gemäss charakteristische Modifikationen (s. Abb. 3–7). Es ist zu erwarten, dass unser OKP zur Unterscheidung sowie zur Identifizierung des Spontannystagmus einigermassen beitragen wird.

ACKNOWLEDGEMENT

We wish to thank Professor Ichiro Kirikae, Head of our Department, for his unlimited help in this investigation. To Professor Frederick G. H. Smith I wish to

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Motofuji-cho 1, Bunkyo-ku Tokyo

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COMMENTS

N mic curves recorded by electronystagmography are worth while ... and serve to give a great deal of important information Nystagmus ... d in normals by optokinetic stimulation is a typical jerky type which ... frequent and large in amplitude is favourable for both recording and ... electronystagmographically

... been said that the greatest drawback of the test for computing ... netic reaction lies in the willingness or otherwise of the test subject to ... upon and follow the moving stripes However this has been ... s problem provided patients are fully cooperative ... mination

... is made to observe the reaction as a whole pattern ... a detailed analysis of each nystagmic curve ... movements obtained by slowing the feeding ... a simple matter to compare recordings obtained ... which would otherwise be lacking in analysis of ... is introduced and interpreted in this paper ... ication of spontaneous nystagmus into small ... for differential diagnosis of causative lesions ... dily modified by weak spontaneous vestibular ... its degree is of important clinical significance in

ZUSAMMENFASSUNG

... r Nystagmus wurde durch die konstante, positive und die sofort ... negative Winkelbeschleunigung des elektromotorischen Drehzy... ... rufen und elektronystagmographisch mit Zeitkonstanten von 6 ... mit 0 1 cm/Sek gefutterte Papier registriert Ein Zweikanal ... tronystagmograph wurde verwendet, indem mit der Zeitkonstante von 6 Sek d... ungef re Augendeviation und von 0 015 die Geschwindigkeit der Deviation zu erzielen erwartet wurde Die Geschwindigkeit der langsamen Phase des Nystagmus beim normalen Menschen nimmt in annahernder Entsprechung der Winkelgeschwindigkeit des Drehzylinders zunachst zu und dann ab Die so gewonnene Registrierungsfigur zeigte eine kuppelahnliche Form Die registrierte Figur soll , optokinetic pattern (OKP) und das Verfahren , optokinetic pattern test (OKP test) bezeichnet werden Die Untersuchung ergab dass sich OKP der Intenzitat des vestibularen Spontannystagmus entsprechend quantitativ verandert, wie in Abb 2 zu sehen ist Bei der Anwendung des Verfahren auf Zentral oder Okularnystagmus zeigte OKP den ursachlichen Lasionen gemass charakteristische Modifikationen (s Abb 3 7) Es ist zu erwarten dass unser OKP zur Unterscheidung sowie zur Identifizierung des Spontannystagmus einigermassen beitragen wird

ACKNOWLEDGEMENT

We wish to thank Professor Ichiro Kirikae Head of our Department for his unlimited help in this investigation To Professor Frederick G H Smith I wish to

genau, als durch die nivellierende Mittelwertbildung die Bedeutung der *einzelnen* Frequenzen für das Hörvermögen verwischt wird. Wir waren zu dieser Form der Auswertung gezwungen, da uns damals maschinelle Verfahren, mit deren Hilfe es allein möglich ist, ein umfangreicheres Zahlenmaterial zu bewältigen, noch nicht zur Verfügung standen.

Sowohl das Ziel, eine exakte und möglichst vielseitige Auswertung der audiologischen Werte zu erhalten, wie auch die vielen Merkmale des klinischen Materials zwangen uns nunmehr dazu, die Aufbereitung der Daten auf eine maschinelle Bearbeitung abzustellen. Von mehreren Verfahren wählten wir das Hollerith-Lochkartensystem der Firma IBM aus, das uns für unser Aufgabenstellung sehr zweckmässig erschien. Mit Hilfe dieses Lochkartenverfahrens sind wir jetzt auch in der Lage, die Hörverluste bei jeder Frequenz für sich getrennt zu behandeln.

Die Erfassung der audiologischen Daten sei hier als erstes beschrieben. Sie ist speziell darauf zugeschnitten, daß diese Zahlen auf einer elektronischen Rechenmaschine (IBM 650) verwertet werden können. Wir halten es für ausreichend, von den Tonschwellenaudiogrammen die Hörverluste über Luft- und Knochenleitung und die Differenz zwischen diesen beiden Werten — die sogenannte Schalleitungskomponente — bei den Frequenzen 250, 500, 1000, 2000, 3000, 4000 und 8000 Hz festzuhalten. Bei den Sprachaudiogrammen übernahmen wir die Intensitätswerte, bei denen 50% der Zahlen richtig verstanden wurden, sowie diejenigen, bei denen 50% bzw. 100% der einsilbigen Testworte richtig erkannt wurden. Außerdem berechneten wir den S.A.I. (Social Adequacy Index nach Silverman) zur Aufnahme in die Lochkarten. Weiterhin haben wir die Meßergebnisse der Hörweitenbestimmung und die des Sprachverstärkertestes nach Zangemeister — eine Hörweitenbestimmung mit einem geeichten Hörgerät — in unseren Lochkartenbeleg aufgenommen. Dies geschah in der Absicht, später zu entscheiden, ob diesen Prüfungen noch eine besondere Bedeutung zukommt oder ob das Tonschwellenaudiogramm zusammen mit dem Sprachaudiogramm für eine eindeutige Indikationsstellung ausreichend ist. Weitere Eintragungen auf dem Lochkartenbeleg beziehen sich auf das Vorliegen des Recruitmentphänomenes, dessen Grades und auf den Ausfall eines Adaptationstestes.

Die Abb. 1 zeigt das Formular, das aus dem Audiogramm die verschiedenen Werte aufnimmt, die später in die Lochkarten gestanzt werden.

Die Lochspaltengruppe 1–4 enthält die Angaben über den Zeitpunkt der audiologischen Prüfung. In der Gruppe 5–10 steht die Journal-Nummer, die es ermöglicht, von einer Lochkarte im Bedarfsfalle auf die Krankengeschichte zurückzugreifen. Das Geschlecht des Patienten ist als positives Vorzeichen bei männlichen, als negatives bei weiblichen Patienten über der 10. Stelle angegeben. Die Spalte 11 gibt Auskunft darüber, ob es sich um das operierte Ohr oder um das andere, nicht operierte Ohr des Patienten handelt. Da wir auch die audiologischen Daten der nicht operierten Ohren mitregistrieren, sind wir in der Lage, Aussagen über eine eventuelle Innenohrreaktion — in positiver wie in negativer Richtung — der nicht operierten

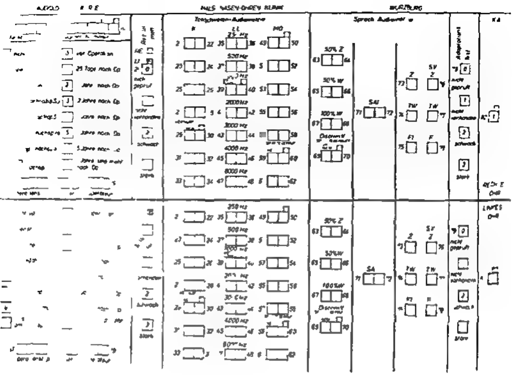


Abb. 1. Lochkartenbeleg für die audiologischen Karten.

Seite zu machen (Wullstein, Naumann und Schmitt). Die Eintragung in Spalte 12 zeigt, ob die Lochkarte das Hörvermögen vor oder nach der Operation angibt. In der Gruppe 13–15 ist die Operationsmethode in einer dreistelligen Verschlüsselung festgehalten. Zu der Gruppe 16–20 braucht keine Erklärung gegeben zu werden. Ob sich die Lochkarte auf ein rechtes oder ein linkes Ohr bezieht, gibt ein + bzw. ein − über der 20. Stelle an. Das Feld von Spalte 21–62 enthält die Werte des Tonschwellenaudiogrammes. Da unsere Audiometer in 5 db-Schritten geeicht sind, erfolgt auch die Eintragung in 5 db-Gruppen. Bei der Knochenleitungs- und Luftleitungsschwelle können ab und an auch negative Werte auftreten. Bei der zur Verfügung stehenden Rechenmaschine können wir nur insgesamt 10 Vorzeichen pro Karte eingeben, die aber an fester d. h. an vorherbestimmter Stelle stehen müssen. Deshalb waren wir gezwungen, diese negativen Zahlen besonders zu verschlüsseln. Wir addierten in einem solchen Fall zu dem absoluten Meßwert eine 1 (6 bedeutet also −5 db, 11 entsprechend −10 db). Nicht mehr meßbare Werte, bei denen der Hörverlust so groß ist, daß die Leistungsgrenze des Audiometers überschritten werden mußte, werden durch die Zahl 99 charakterisiert. In den Vorzeichenstellen der Spalten 30 und 40 finden sich Angaben über die Art der Vertäubung, während die Vorzeichenstelle in Spalte 60 anzeigt, ob das Sprachaudiogramm vorliegt (+) oder nicht (−), ähnlich wie das Vorzeichen über Spalte 70 Auskunft gibt, ob die Hörweitenmessung im vorliegenden Fall durchgeführt wurde. Durch die beiden letzterwähnten Vorzeichenstellen kann der Ablauf des elektronischen Auswertungsprogrammes erheblich beschleunigt werden. Zu den Eintragungen in Spalte 63–72 sind keine Erklärungen nötig, die Hörweiten in Spalte 73–78 werden verschlüsselt

Universitäts-Hals-Nasen-Ohrenklinik Würzburg

Chirurgische Karte
(Tympanoplastik)

Datum	Lfd. Nummer	Geschlecht	Alter bei Op.
Operationstyp	Operationstyp vor Nachoperation		Diagnose

Behandlung und Zustände vor Op.
Vorbehandlung
Tubendurchgängigkeit
N. facialis
Sekretion

Zustand bei Revision
Indikation
Transplantat über Pauke

Zustand bei Atresie

Zustände während der Op.
Perforation
Pars tensa
Pars flaccida
Hammer
Amboß
Epitympanon
Mesotympanon
Hypotympanon
Aditus und Antrum
Warzenfortsatz
Promontorium
Tubeneingang
Tubendurchgängigkeit
Ovale Nische
Beweglichkeit der Fußplatte
Runde Nische
Wechseldruck
N. facialis
Dekompression
Vorgehen bei Dekompression
Bogengangsfistel
Andere Komplikationen
Spontantypen

Operatives Vorgehen
Transplantatentnahme
Art des Transplantates
Kontrolleinblicke

Operatives Vorgehen (Fortsetzung)
Präparation des Trommelfelles
Präparation der Ossicula
Vorgehen an der Brücke
Präparation des Epitympanons
Präparation des Hypotympanons
Präparation des Mastoids
Präparation des Aditus und Antrums
Präparation des Promontoriums
Präparation der Tubenmündung
Präparation der Tube
Präparation der ovalen Nische
Präparation der runden Nische
Tamponade
Prognose
Blutstillung während der Operation
Spülflüssigkeiten
Schleimhautersatz
Präoperative Medikation
Narkose
Intubation
Operateur

Nachbehandlung und Heilungsverlauf
Lokalbehandlung
Allgemeinbehandlung
Tubendurchlüftung
Beweglichkeit des Transplantates
Perforation
Andere pathol. Befunde
Komplikationen nach Op.
Allgemeine Komplikationen

Ergebnisse bei Entlassung
Operationshöhle
Transplantat
Perforation
Beweglichkeit des Transplantates
Durchlüftung

Abb. 2. Disposition für die chirurgischen Lochkartenbelege

angegeben. Die letzte Spalte enthält die Kennlochung für die audiologischen Karten. Diese Kennzeichnung ist wichtig, da sie ermöglicht, die audiologischen Karten maschinell von anderen Karten zu trennen, wenn diese gemeinsam bearbeitet werden.

Über die Art der Registrierung der vielen Merkmale aus der Pathologie des Ohres, der Einzelheiten der angewandten Operationstechnik und des

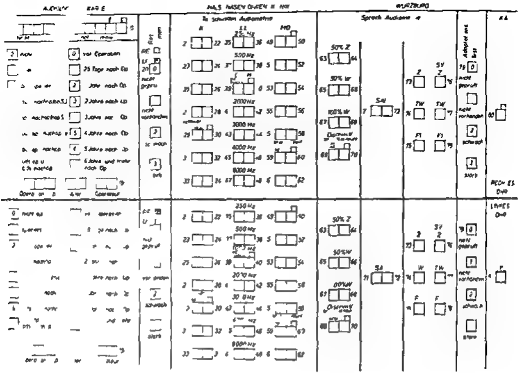
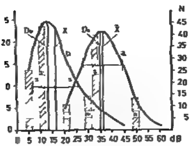


Abb. 1. Lochkartenbeleg für die audiologischen Karten.

Stelle zu machen (Wullstein, Naumann und Schmitt). Die Eintragung in Spalte 12 zeigt, ob die Lochkarte das Hörvermögen vor oder nach der Operation angibt. In der Gruppe 13–15 ist die Operationsmethode in einer dreistelligen Verschlüsselung festgehalten. Zu der Gruppe 16–20 braucht keine Erklärung gegeben zu werden. Ob sich die Lochkarte auf ein rechtes oder ein linkes Ohr bezieht, gibt ein + bzw. ein − über der 20. Stelle an. Das Feld von Spalte 21–62 enthält die Werte des Tonschwellenaudiogrammes. Da unsere Audiometer in 5 db Schritten geeicht sind, erfolgt auch die Eintragung in 5 db Gruppen. Bei der Knochenleitungs- und Luftleitungsschwelle können ab und an auch negative Werte auftreten. Bei der zur Verfügung stehenden Rechenmaschine können wir nur insgesamt 10 Vorzeichen pro Karte eingeben, die aber an fester d. h. an vorherbestimmter Stelle stehen müssen. Deshalb waren wir gezwungen, diese negativen Zahlen besonders zu verschlüsseln. Wir addierten in einem solchen Fall zu dem absoluten Meßwert eine 1 (6 bedeutet also −5 db, 11 entsprechend −10 db). Nicht mehr meßbare Werte, bei denen der Hörverlust so groß ist, daß die Leistungsgrenze des Audiometers überschritten werden mußte, werden durch die Zahl 99 charakterisiert. In den Vorzeichenstellen der Spalten 30 und 40 finden sich Angaben über die Art der Vertäubung, während die Vorzeichenstelle in Spalte 60 anzeigt, ob das Sprachaudiogramm vorliegt (+) oder nicht (−), ähnlich wie das Vorzeichen über Spalte 70 Auskunft gibt, ob die Hörweitenmessung im vorliegenden Fall durchgeführt wurde. Durch die beiden letzterwähnten Vorzeichenstellen kann der Ablauf des elektronischen Auswertungsprogrammes erheblich beschleunigt werden. Zu den Eintragungen in Spalte 63–72 sind keine Erklärungen nötig, die Hörweiten in Spalte 73–78 werden verschlüsselt



gskurven ler Schalleitungskomponenten bei 1000 Hz 183 Falle m e Kurve b nach vorderer Crurotomie

arithmetische Mittelwert (a M) einer Verteilung der l berechnet wird

$$x = \frac{1}{N}\sum_{i}^{m}(n_i x_i) \tag{1}$$

r Mittelwert N Gesamtzahl der Beobachtungen n_i = ommen des Merkmales N und x Große des Merk hlauft samtliche Werte von 1 bis m wobei m stets kleiner

l in der Abb 3 durch die beiden senkrechten Linien ilen 36 4 und 16 4 db Schalleitungskomponente wieder t an diesem Beispiel daß die a M nicht auf die Abs denen die großte Haufigkeit zukommt sie liegen viel sen Es handelt sich somit um rechtsschiefe Verteilungen ruppen die die großte Haufigkeit haben bezeichnet man l die in Abb 3 mit D_a bzw D_b angeben sind Um zum gen ob es sich um eine hochgipfelige schmale oder um breite Verteilungskurve handelt kann die mittlere quad ng vom a M die sog Streuung s angegeben werden

$$s = \pm\sqrt{\frac{{}_i(x_i - x)}{N-1}} \tag{2}$$

beinhaltet daß die Verteilung nieder und flach kleine hoch und schmal ist Die Streuung ist bei den Kurven a lurch die horizontalen symmetrisch zum a M liegenden gegeben

sehen daß man entweder nur die Lage von x_b oder die als Maß fur den Erfolg einer gehörverbessernden O hrmechanischem Standpunkt aus gesehen — kann Je grosser x_a—x_b desto gunstiger ist vorliegenden Kollektiv Selbstredend konnte

Ac

Heilungsverlaufes verschafft uns die Abb. 2 einen Überblick. Bei den hier angeführten Stichworten handelt es sich nur um Überschriften von einigen Teilgebieten, die in den Lochlisten durch viele weitere Angaben erschöpfend behandelt werden. Der zur Verfügung stehende Raum verbietet jedoch die Veröffentlichung der gesamten Lochbelege. Die hier erwähnten Angaben werden in die sog. chirurgischen Karten gestanzt; selbstverständlich sind diese chirurgischen Karten an einer eigenen Kennlochung in der Spalte 80 zu erkennen. Für die Tympanoplastik sind je 3 Lochkarten mit je 80 Spalten zur chirurgischen Registrierung nötig. Bei der Fenestration und der Stapedolyse genügt je eine 80 spaltige Lochkarte. Es besteht kein Hinderungsgrund, bei Bedarf noch weitere Karten zur Ergänzung anzufügen. Darüber hinaus existieren noch besondere Karten für die Befunde bei Nachuntersuchungen. Somit verwenden wir zur statistischen Bearbeitung 5 Lochkartenbelege: 1) audiologischer Beleg (1 Lochkarte pro Ohr und Zeitpunkt), 2) chirurgischer Beleg Tympanoplastik (3 Lochkarten), 3) chirurgischer Beleg Fenestration (1 Lochkarte), 4) chirurgischer Beleg Stapedolyse (1 Lochkarte).

Auswertung der audiologischen Daten

Bei den audiologischen Werten (Schwelle für Knochenleitung, Luftleitung, Schalleitungskomponente etc.) innerhalb eines bestimmten Kollektivs (z. B. derjenigen Otosklerosekranken, an denen eine Crurotomie durchgeführt wurde) handelte es sich um beobachtete Häufigkeiten bestimmter Ereignisse. So kann beispielsweise gezählt werden, daß es z_1 mal vorgekommen ist, daß die Schwelle der Knochenleitung für 1000 Hz bei 10 db Hörverlust erreicht wurde oder z_2 mal bei einem Wert von 20 db Hörverlust. Aus diesen Häufigkeitszahlen z lassen sich die Häufigkeitsverteilungen gewinnen. Die Abb. 3 zeigt anhand von 183 Patienten, die nach der Methode von Fowler (vordere Crurotomie) operiert wurden, auf der Ordinate, wie oft die Schalleitungskomponente den auf der Abszisse angegebenen Wert hatte. Die Kurve *a* bezieht sich auf die Schalleitungskomponente bei 1000 Hz vor der Operation, die Kurve *b* auf dieselben Werte nach der Operation. Für alle gemessenen Frequenzen lassen sich ähnliche Verteilungskurven zeichnen, ebenso für die Meßpunkte der Knochen- oder der Luftleitung und für die Sprachaudiogrammwerte. Diese Darstellungsart gibt uns ein aufschlußreiches Bild über das Ausgangsmaterial und die durch die Operation hervorgerufenen Veränderungen. Für vergleichende Untersuchungen ist sie jedoch nur bedingt zu gebrauchen, da sie sehr viele Einzelbilder erfordert, die nur mühevoll, nämlich Kurvenpunkt für Kurvenpunkt, miteinander verglichen werden können. Für vergleichende Betrachtung ist es vorteilhaft, auf die vielen Einzelheiten, die die Häufigkeitsverteilung bietet, zu verzichten und nur einige die Verteilungskurve charakterisierende Maßzahlen miteinander in Beziehung zu setzen. Die wichtigste dieser Maßzahlen für

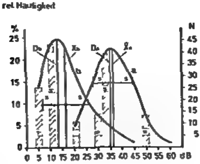


Abb. 3. Häufigkeitsverteilungskurven der Schalleitungskomponenten bei 1000 Hz. 183 Fälle. Kurve *a* vor vorderer Crurotomie, Kurve *b* nach vorderer Crurotomie

unseren Zweck ist der arithmetische Mittelwert (a. M.) einer Verteilung, der nach folgender Formel berechnet wird

$$x = \frac{1}{N}\sum_{i}^{m}(z_i x_i) \tag{1}$$

wo x = arithmetischer Mittelwert, N = Gesamtzahl der Beobachtungen, z_i = Häufigkeit des Vorkommens des Merkmales X, und x_i = Größe des Merkmales X. Index i durchläuft sämtliche Werte von 1 bis m, wobei m stets kleiner als N ist.

Dieser a. M. wird in der Abb. 3 durch die beiden senkrechten Linien ($\bar{x}_a$, $\bar{x}_b$) bei den Werten 36.4 und 16.4 db Schalleitungskomponente wiedergegeben. Man sieht an diesem Beispiel, daß die a. M. nicht auf die Abszissenpunkte fallen, denen die größte Häufigkeit zukommt, sie liegen viel mehr rechts von diesen. Es handelt sich somit um rechtsschiefe Verteilungen. Diejenigen Wertegruppen, die die größte Häufigkeit haben, bezeichnet man als die Dichtemittel, die in Abb. 3 mit D_a bzw. D_b angegeben sind. Um zum Ausdruck zu bringen, ob es sich um eine hochgipfelige schmale oder um eine niedergipfelige breite Verteilungskurve handelt, kann die mittlere quadratische Abweichung vom a. M., die sog. Streuung s angegeben werden

$$s = \pm\sqrt{\frac{\overline{z_i(x_i - x)}}{N-1}}. \tag{2}$$

Große Streuung beinhaltet, daß die Verteilung nieder und flach, kleine Streuung, daß sie hoch und schmal ist. Die Streuung ist bei den Kurven *a* und *b* in Abb. 3 durch die horizontalen, symmetrisch zum a. M. liegenden Linien ($\pm s$) wiedergegeben.

Es ist leicht einzusehen, daß man entweder nur die Lage von $\bar{x}_b$ oder die Differenz von x_a—x_b als Maß für den Erfolg einer gehörverbessernden Operation — vom mittelohrmechanischem Standpunkt aus gesehen — bei einer Frequenz betrachten kann. Je grosser x_a—$\bar{x}_b$, desto günstiger ist das Operationsresultat in dem vorliegenden Kollektiv. Selbstredend könnte man auch

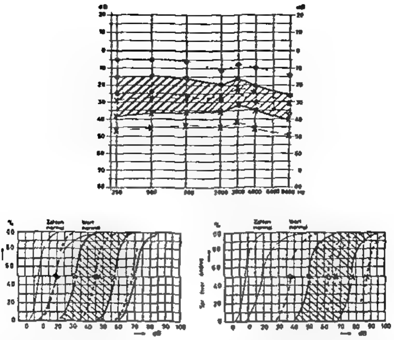


Abb 4 Vordere Crurotomie 183 Fälle Oben Mittelwerte der Schalleitungskomponenten ×——×, vor der Operation O——O nach der Operation ×—× mittlere Abweichung vor der Operation O O mittlere Abweichung nach der Operation Unten links Mittelwerte für 50%iges Zahlenverständnis rechts Mittelwerte für 50%iges Wortverständnis —×— vor der Operation —O— nach der Operation × mittlere Abweichung vor der Operation O *mittlere Abweichung nach der Operation*

die Lage von D_b oder die Differenz D_a—D_b als Kriterium heranziehen man erhielte nach Abb 3 hierdurch sogar ein besseres Ergebnis Bei dem Dichtemittel werden aber nicht die Extremwerte mitberücksichtigt sondern nur die Verteilung in den am stärksten besetzten mittleren Wertegruppen d h daß der flache Auslauf der Verteilungskurve nach rechts nicht bewertet wird Uns scheint daher die Angabe des a M einen korrekteren Beurteilungsmaßstab zu geben da hier auch die ungünstigen Resultate einen Niederschlag finden Ebenso ist es verständlich daß eine Operationsmethode vorzuziehen ist die bei gleicher Lage von a_b bzw gleicher Differenz a_a—a_b eine kleinere Streuung hat Diese Operationsart würde besser reproduzierbare Ergebnisse liefern als eine mit einer großen Streuung Aus diesem Grunde geben wir zu sämtlichen Mittelwerten auch die zugehörige Streuung an

Faßt man die a M mit ihren zugehörigen Streuungen für alle Testfrequenzen zusammen so ergibt sich das in Abb 4 oben gezeigte Diagramm Auf der Abszisse sind die Frequenzen in Hz auf der Ordinate die Schalleitungskomponenten in db angegeben Die untere starke Linie — mit × gekennzeichnet — repräsentiert die a M der Schalleitungskomponenten vor der Operation (Übersicht über alle Kurven *a* der Abb 3 bei den verschiedenen Frequenzen) die gestrichelten — ebenfalls durch × markierten Linien die

entsprechenden Streuungen. Die obere dicke Linie — mit o hervorgehoben — ist die Übersicht über alle Kurven *b* der Abb. 3, d. h. der a. M. der Schalleitungskomponenten nach der Operation.

Die zugehörige Streuung veranschaulichen die punktierten Linien. Die schraffierte Fläche ist die Differenz zwischen den Werten a_a—a_b, der Hauptmaßstab für die durch den Eingriff erzielte Verbesserung der Mittelohrmechanik.

Welchen Hörgewinn die einzelnen Operationsmethoden für das praktische Leben bringen, zeigt uns die Abb. 4 im unteren Teil des Bildes. In der linken Hälfte ist der a. M. des Hörgewinnes im Sprachaudiogramm gemessen am Zahlentest (entspricht in etwa dem amerikanischen Spondee-Test) wiedergegeben, während die rechte Hälfte den a. M. des Gewinnesanh and der Prüfung mit einsilbigen Wörtern (entspricht dem PB-Test) demonstriert. Die gestrichelten Linien sind wieder die Streuungsmaße.

Die Abb. 13 klärt uns über das Verhalten der Knochenleitung nach einer Operation auf. Es sind darin die a. M. der Veränderungen in der Knochenleitung zwischen dem Zeitpunkt vor und nach der Operation bei den verschiedenen Testfrequenzen und die zugehörigen Streuungen eingetragen. Ein Anstieg der stark ausgezogenen Linie über die Nullinie bedeutet, daß durch die Operation eine Verbesserung der Mittelwerte der Knochenleitung eingetreten ist. Ein Absinken unter dieses Niveau weist auf eine entsprechende Verschlechterung hin. Eine Schwierigkeit in der Darstellung sei hier noch besprochen. Verschiedentlich liegt ein Wert der Knochenleitung entweder schon vor der Operation oder erst nach dem Eingriff so tief, daß er mit dem Audiometer nicht mehr gemessen werden kann. Wir können dann sagen, daß der Patient für diese Frequenz taub ist oder taub wurde. Diese unter der Meßgrenze des Audiometers liegenden Punkte scheiden für die Berechnung der a. M. aus, da von ihnen das zur Mittelwertbildungen notwendige Produkt Häufigkeit mal Größe des Wertes nicht gebildet werden kann.

Wir haben uns daher entschlossen, bei jeder Frequenz die Häufigkeit dieses Ereignisses (in Prozent) am Fuße der Ordinate anzugeben, wobei sich die in der oberen Zeile stehenden Ziffern auf den Zustand vor der Operation beziehen und somit zur Vervollständigung des Bildes über das Ausgangskollektiv dienen, während die untere Zeile die Häufigkeit der Taubheit bei der entsprechenden Tonhöhe nach dem Eingriff bezeichnet. Aus der Differenz dieser Werte kann in der Zusammenschau mit dem Verlauf der a. M.-Linie auf das Operationsrisiko der betreffenden Operation geschlossen werden. Selbstverständlich kann auch die Schalleitungskomponente nicht angegeben werden, wenn der zugeordnete Knochenleitungswert nicht zu messen war. Hierdurch kommt es, daß sich die Mittelwerte der Schalleitungskomponenten bei den verschiedenen Testtönen nicht auf dieselbe Gesamtzahl N (Formel 1) beziehen.

Aus dem bisher Gesagten geht hervor, daß wir mit Hilfe von zwei Diagrammen, Abb. 4 und 13, in der Lage sind, den audiologischen Erfolg eines gehörverbessernden Eingriffes zu einem bestimmten Zeitpunkt im Hinblick

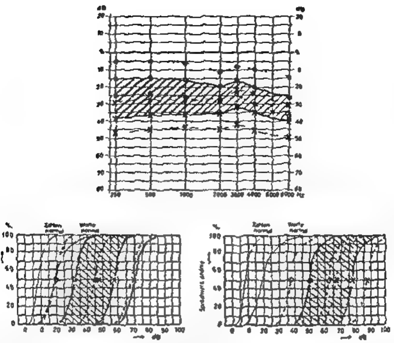


Abb. 4. Vordere Crurotomie 183 Fälle. Oben: Mittelwerte der Schalleitungskomponenten ×——×, vor der Operation ○——○, nach der Operation ×—×, mittlere Abweichung vor der Operation, ○- ○ mittlere Abweichung nach der Operation. Unten links: Mittelwerte für 50%iges Zahlenverständnis, rechts: Mittelwerte für 50%iges Wortverständnis —×—, vor der Operation, —○—, nach der Operation, - × , mittlere Abweichung vor der Operation, - ○ , mittlere Abweichung nach der Operation.

die Lage von D_b oder die Differenz D_a-D_b als Kriterium heranziehen, man erhielte nach Abb. 3 hierdurch sogar ein besseres Ergebnis. Bei dem Dichtemittel werden aber nicht die Extremwerte mitberücksichtigt, sondern nur die Verteilung in den am stärksten besetzten mittleren Wertegruppen, d. h. daß der flache Auslauf der Verteilungskurve nach rechts nicht bewertet wird. Uns scheint daher die Angabe des a. M. einen korrekteren Beurteilungsmaßstab zu geben, da hier auch die ungünstigen Resultate einen Niederschlag finden. Ebenso ist es verständlich, daß eine Operationsmethode vorzuziehen ist, die bei gleicher Lage von $\bar{x}_b$ bzw. gleicher Differenz $\bar{x}_a-\bar{x}_b$ eine kleinere Streuung hat. Diese Operationsart würde besser reproduzierbare Ergebnisse liefern als eine mit einer großen Streuung. Aus diesem Grunde geben wir zu sämtlichen Mittelwerten auch die zugehörige Streuung an.

Faßt man die a. M. mit ihren zugehörigen Streuungen für alle Testfrequenzen zusammen, so ergibt sich das in Abb. 4 oben gezeigte Diagramm. Auf der Abszisse sind die Frequenzen in Hz, auf der Ordinate die Schalleitungskomponenten in db angegeben. Die untere starke Linie — mit × gekennzeichnet — repräsentiert die a. M. der Schalleitungskomponenten vor der Operation (Übersicht über alle Kurven a der Abb. 3 bei den verschiedenen Frequenzen), die gestrichelten, — ebenfalls durch × markierten Linien die

um das gleiche Kollektiv von 183 Crurotomien. Aus dem Diagramm ist zu entnehmen, daß in 93,9% der Fälle eine Verkleinerung der Schalleitungsstörungen um 5–45 db eintritt, in 6,1% keine Änderung bzw. eine Vergrößerung um 5–10 db. Der häufigste Wert, das Dichtemittel, lag mit 17% bei einer Verbesserung um 20 db. Der a. M. ā fällt hier mit dem Dichtemittel zusammen; es liegt somit eine fast völlig symmetrische Verteilung vor. Die Streuung s beträgt ±10,4 db. Die Abb. ▪ ist daraus entstanden, daß man die a. M. für alle Frequenzen mit den zugehörigen Streuungen zu einem Diagramm vereinigt, ähnlich wie bei der Abb. 4 in der oberen Hälfte. Bei jeder Frequenz ist zusätzlich noch der Prozentsatz der Verbesserungen (obere Zeile) bzw. der Verschlechterungen (untere Zeile) angegeben. Dieses Diagramm könnte als Prognose-Diagramm bezeichnet werden.

Gemeinsame Verarbeitung audiologischer und klinisch-chirurgischer Daten

Um die Möglichkeiten der Auswertung und die Brauchbarkeit des entwickelten statistischen Verfahrens zu überprüfen und um aus seiner probatorischen Anwendung Erfahrungen zu sammeln, haben wir zunächst nur einen Teil des uns zur Verfügung stehenden Materials Wullsteins aus der Siegener und Würzburger Klinik von jetzt 6000 gehörverbessernden Eingriffen verarbeitet und zwar insgesamt 1227 Operationen. Diese setzen sich zusammen aus

483 Tympanoplastiken, 88 Fenestrationen und 656 Stapedolysen.

Bei den Stapedolysen kamen folgende operativen Methoden zur Anwendung:

76 indirekte Mobilisationen (nach Rosen), 236 direkte Mobilisationen (nach Rosen etc.), 183 Crurotomien (nach Fowler) und 161 Fenestrationen im ovalen Fenster (nach Shea und Shea–Portmann).

Die audiologische Auswertung erstreckte sich auf alle 1227 Operationen. Die sich hieraus ergebenden Einzelheiten werden wir zu einem späteren Zeitpunkt, wenn wir über das ganze Operationsgut berichten können, veröffentlichen; die vorliegende Arbeit soll nur einen Einblick in unsere neue Bearbeitungsmethode geben. Aus diesem Grunde bringen wir nur eine erste orientierende Auswertung der pathologisch-anatomischen, operationstechnischen und klinischen Angaben der chirurgischen Karte bei den Tympanoplastiken.

Die Bearbeitung der in diesen Karten festgehaltenen Einzelpositionen (insgesamt 1035) macht keine Schwierigkeit. Hier können fast sämtliche Fragestellungen mit Hilfe einer Sortiermaschine mit Zähleinrichtung beantwortet werden. Nur um ein Beispiel über die Auswertungsmöglichkeiten, die durch wenige Sortiergänge erschlossen werden können, zu geben, seien einige Zahlenangaben aus der Bearbeitung der chirurgischen Karten der Tympanoplastik herausgegriffen.

Von 483 Kranken, bei denen eine Tympanoplastik durchgeführt wurde, litten an einer

chron Otitis media mit Cholesteatom	210 = 43 %.
chron. Otitis media mit Schleimhauteiterung	180 = 38 %.
chron Otitis media ohne Sekretion	93 = 19 %.

In 58 Fällen (12 %) war eine Radikaloperation, in 14 Fällen (3 %) eine Antrotomie der Tympanoplastik vorausgegangen. Einer Tympanosklerose begegneten wir in 15 Fällen (3,2 %) An einer beiderseitigen chronischen Mittelohrentzündung litten 173 Patienten; von diesen ließen 131 (76 %) eine Tympanoplastik auf beiden Ohren vornehmen Bei den Cholesteatomfällen hatte sich 9-mal das Cholesteatom hinter geschlossenem oder wieder verschlossenem Trommelfell entwickelt (4,3 %), randständige Defekte der Pars tensa wurden bei 141 Kranken (67 %) beobachtet, Kuppelraumdefekte bei 60 Kranken (28,7 %) Zwei Drittel zeigten fötide Sekretion, bei einem Drittel war zum Zeitpunkt der Operation keine Sekretion vorhanden In der postoperativen Heilungsphase der Tympanoplastik gewinnt das Verhalten des von uns ausschließlich verwendeten freien Hauttransplantates Interesse. Bei 395 Tympanoplastiken (82 %) heilte das Transplantat ohne Störung ein, kleine Nekrosen in den Randbezirken des Hautlappens in der Operationshöhle fanden sich 47-mal (9,5 %), größere Nekrosen 7-mal (1,5 %); Nekrosen uber der Paukenhöhle waren nur in 35 Fällen (7 %) zu beobachten In 16 Fällen kam es zu einer Ablösung des Transplantates im Bereich der vorderen Gehörgangswand, den sog Randablösungen (3,5 %) Somit traten in 51 Fällen (10,5 %) Recidivperforationen auf Ihre Verteilung auf die verschiedenen Formen der Mittelohrentzundung ist praktisch gleichmäßig (bei Cholesteatom 9 %, bei Schleimhauteiterung 11 % und bei trockenen Trommelfelldefekten 12 %) Ein zweiter Eingriff nach Tympanoplastik war in 59 Fällen (12 %) notwendig

Alle diese Angaben uber die pathologischen Zustände des Ohres, über die spezielle Operationstechnik und uber den Verlauf und das Resultat der Abheilungsphase können nunmehr ohne weiteres in Beziehung zu ihrer funktionellen Wirksamkeit, d h den resultierenden audiologischen Daten, gesetzt werden Anhand des Ablaufschemas in Abb 7 soll erklärt werden, wie die gemeinsame Auswertung der chirurgischen und audiologischen Merkmale vorgenommen wird Es soll z B darüber Auskunft erteilt werden, mit welcher Hörverbesserung und mit welchem Risiko gerechnet werden kann, wenn bei einer Otitis media chronica mit Cholesteatombildung bei bestehender Sekretion eine Tympanoplastik Typ IV vorgenommen wird Wir haben dieses Beispiel mit den ersten 483 auf Lochkarten registrierten Tympanoplastiken als eine der vielen Proben auf die Brauchbarkeit unseres Systemes durchgerechnet Als Ausgangsmaterial liegen zwei Kartenstapel vor, die audiologischen und die chirurgischen Karten Jedes dieser Pakete ist unter sich so geordnet, daß zuerst die Karten mit der niedrigsten Journalnummer liegen Außerdem liegen unter jeder Journalnummer die verschie-

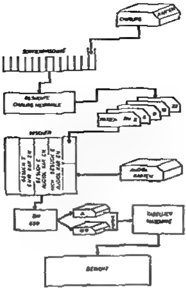


Abb 7 Ablaufschema

denen Karten so daß die ältesten zuerst (Zustand vor der Operation), die jüngsten zu unterst (letzte verfügbare Nachuntersuchung) aufgefunden werden Wir suchen als erstes aus den chirurgischen Karten alle diejenigen heraus, die in den Spalten 13 15 die Kennlochung für die Tympanoplastik Typ IV tragen Von diesen suchen wir auf der Sortiermaschine diejenigen heraus, die das Merkmal "Cholesteatom" und "Sekretion" haben Dies sind die gesuchten Fälle Um die zugehörigen audiologischen Karten zu bekommen, müssen wir lediglich die gefundenen chirurgischen Karten als sog Suchkarten auf einen Kartenmischer geben und uns von diesem die entsprechenden audiologischen Karten auf Grund des Vergleiches der Journalnummern und der Seite des betreffenden Ohres aussortieren lassen Die so erhaltenen audiologischen Karten (es waren bei unserem Testbeispiel noch 78 Fälle) werden dann der Auswertung auf der IBM 650 zugeführt Diese liefert das Ergebnis in Lochkarten, die mit Hilfe einer Tabelliermaschine

Prozentsatz der Fälle mit Schalleitungskomponente kleiner als 30 dB

Testfrequenz Hz	vor der Operation	nach der Operation
250	40,4	70,7
500	38,1	70,5
1000	27,5	62,9
2000	40,1	79,5
3000	46,3	58,[illegible]
4000	43,4	57,9
8000	42,0	60,5

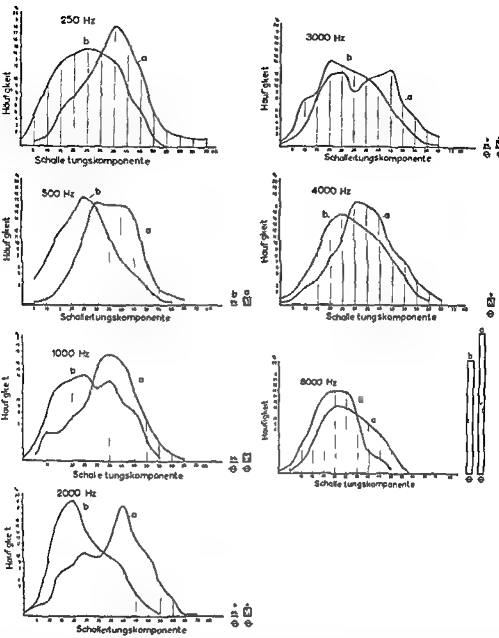


Abb. 8a. Tympanoplastik Typ IV (Cholesteatom) bei bestehender Sekretion. 78 Fälle. Häufigkeitsverteilungen der Schalleitungskomponenten. *a*, vor der Operation, *b*, nach der Operation. ⊖, Prozentsatz der über die Leistungsgrenze des Audiometers liegenden Schalleitungskomponenten. *a*, vor der Operation, *b*, nach der Operation.

in einen geschriebenen Bericht umgewandelt werden. Aus diesem entnehmen wir alle die Daten, die wir zur Aufstellung der Abb. 8 benötigen. Die Abb. 8*a* zeigt uns die Verteilungskurven der Schalleitungskomponente vor und nach der Operation bei den verschiedenen Testfrequenzen. Schalleitungskomponenten zwischen 0 und 30 db wurden nach der nebenstehenden Tabelle vorgefunden.

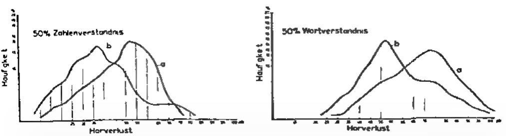


Abb. 8*b*. Tympanoplastik Typ IV (Cholesteatom bei bestehender Sekretion). 48 Fälle. Häufigkeitsverteilung des 50%igen Zahlenverständnisses *a* vor der Operation, *b* nach der Operation. Häufigkeitsverteilung des 50%igen Wortverständnisses *a* vor der Operation, *b* nach der Operation.

Die Abb. 8*b* gibt die Verteilungskurven für das 50%ige Zahlen- und Wortverständnis vor und nach der Operation wieder. Aus Abb. 8*c* ist zu ersehen, daß die Innenohrleistung in dem vorliegenden Operationsgut teilweise stark vorgeschädigt war. Durch den Eingriff ist es jedoch zu keiner Schädigung der Innenohrfunktion, gemessen an der Knochenleitung, gekommen, sondern im Gegenteil zu einer leichten, wenn auch nicht statistisch signifikanten Besserung. In der Abb. 8*c* ist der Übersichtlichkeit halber die Darstellung der a. M. der Knochenleitung vor und nach der Operation gewählt. Stellt man sich nunmehr vor, daß auch die entsprechenden Bilder für die Zeiträume vom Zustand vor bis ein, zwei oder mehr Jahren nach der Operation vorliegen, so kann man verstehen, daß mit dieser Art der statistischen Darstellung ein zuverlässiger Überblick über die audiologische Entwicklung einer bestimmten Patientengruppe gewonnen werden kann.

Das Verhalten der Innenohrleistung bei verschiedenen Operationsmethoden der Otosklerose

In den Abb. 9 bis 16 und 19 bis 20 sind die a. M. der Veränderung der Knochenleitung zu den bei den einzelnen Diagrammen angegebenen Zeit-

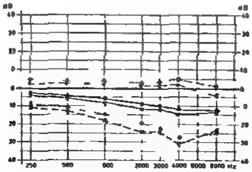


Abb. 8*c*. Tympanoplastik Typ IV (Cholesteatom bei bestehender Sekretion). 78 Fälle. ——×, Mittelwerte der Knochenleitung vor der Operation. O——O Mittelwerte der Knochenleitung nach der Operation. × - - × mittlere Abweichung vor der Operation. ● - - O mittlere Abweichung nach der Operation.

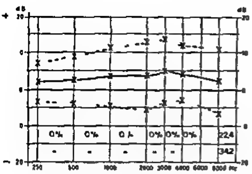


Abb. 9

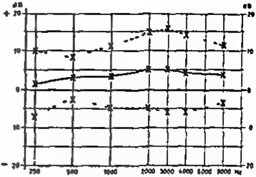


Abb. 10

Abb. 9. Indirekte Mobilisation 70 Fälle ×——×, Durchschnittliche Änderung der Knochenleitung zwischen dem Zeitpunkt vor und 1 Monat nach der Operation × ×, mittlere Abweichung.

Abb. 10. Indirekte Mobilisation 16 Fälle × ×, Durchschnittliche Änderung der Knochenleitung zwischen dem Zeitpunkt vor der Operation und 1 Jahr nach der Operation × ×, mittlere Abweichung.

punkten und bei den verschiedenen Operationsmethoden dargestellt. Es handelt sich um die gleiche Darstellungsart wie bei der schon besprochenen Abbildung 13. Die Abb. 9 und 10 bringen deutlich zum Ausdruck, daß bei der indirekten Mobilisation einen Monat nach der Operation ein geringer Anstieg der Knochenleitung vorzufinden ist. Auch ein Jahr nach dem Eingriff ist noch etwa dieselbe Verbesserung nachzuweisen. Bei der direkten Mobilisation tritt nach der Operation zunächst ein kleiner Abfall in der Innenohrleistung für die Frequenz 8000 Hz auf (Abb. 11), der sich aber nach Ablauf eines Jahres wieder ausgleicht (Abb. 12). Bei der Crurotomie (Abb. 13 und 14) tritt das gleiche Verhalten zutage, nur etwas ausgeprägter als bei der direkten Mobilisation. Bei der Fenestration im ovalen Fenster nach Shea oder Shea–Portmann ist

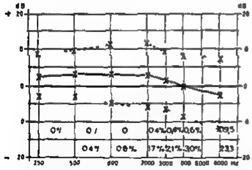


Abb. 11

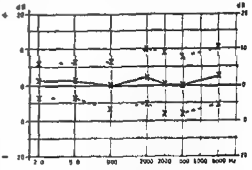


Abb. 12

Abb. 11. Direkte Mobilisation 230 Fälle ×——× Durchschnittliche Änderung der Knochenleitung zwischen dem Zeitpunkt vor und 1 Monat nach der Operation × × mittlere Abweichung.

Abb. 12. Direkte Mobilisation 49 Fälle ×—— Durchschnittliche Änderung der Knochenleitung zwischen dem Zeitpunkt vor der Operation und 1 Jahr nach der Operation × × mittlere Abweichung.

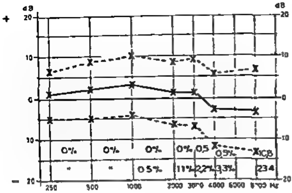


Abb 13

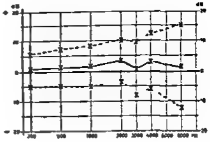


Abb 14

Abb 13 Vordere Crurotomie 184 Fälle ×——×, Durchschnittliche Änderung der Knochenleitung zwischen dem Zeitpunkt vor und 1 Monat nach der Operation ×---×, mittlere Abweichung

Abb 14 Vordere Crurotomie 19 Fälle ×——×, Durchschnittliche Änderung der Knochenleitung zwischen dem Zeitpunkt vor der Operation und 1 Jahr nach der Operation, ×---×, mittlere Abweichung

der postoperative Innenohrabfall am stärksten ausgebildet (Abb 15) Auch hier kommt es im Laufe des ersten Jahres zu einer Wiedererholung der Innenohrfunktion, es wird jedoch der Ausgangswert nicht wieder erreicht (Abb 16) Diese Feststellungen bestätigen die von Wullstein u a Autoren geäußerte Vermutung, daß die Gefahr der Innenohrschädigung mit dem Ausmaß der Manipulationen im ovalen Fenster wächst Wir haben uns die Frage vorgelegt, ob die starke Reaktion des Innenohres bei der Fenestration im ovalen Fenster möglicherweise dadurch vorgetäuscht ist, daß diese

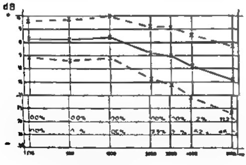


Abb 15

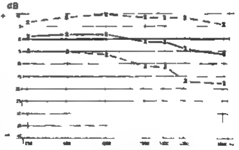


Abb 16

Abb 15 Fenestration im ovalen Fenster 161 Fälle ——, Durchschnittliche Änderung der Knochenleitung zwischen dem Zeitpunkt vor und 1 Monat nach der Operation ×, mittlere Abweichung

Abb 16 Fenestration im ovalen Fenster 33 Fälle ——, Durchschnittliche Änderung der Knochenleitung zwischen dem Zeitpunkt vor und 1 Jahr nach der Operation, mittlere Abweichung

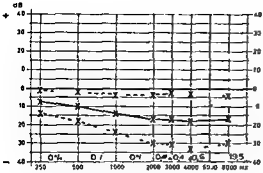


Abb. 17

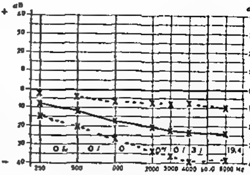


Abb. 18

Abb. 17. Direkte Mobilisation 236 Fälle. x——x, Mittelwerte der Knochenleitung vor der Operation; x---x, mittlere Abweichung.

Abb. 18. Fenestration im ovalen Fenster nach Shea-Portmann. x——x, Mittelwerte der Knochenleitung vor der Operation. x- -x, mittlere Abweichung.

Operationsmethode nur bei solchen Patienten angewandt wurde, deren Innenohrleistung schon vor der Operation beträchtliche Einbussen aufwies. Abb. 17 zeigt die a. M. der Knochenleitung vor der Operation bei dem Kollektiv der direkten Mobilisationen und die Abb. 18 bei dem der Fenestrationen im ovalen Fenster. Zwischen diesen beiden Kollektiven bestanden die *grössten präoperativen Abweichungen, die Berechnung der Signifikanz ergab* jedoch nur einen geringen gesicherten Unterschied bei der Frequenz von 8000 Hz. Die stärkere Reaktion der Knochenleitung nach der Operationsmethode von Shea bzw. von Shea–Portmann ist demnach auf das Verfahren selbst, nicht aber auf die Anwendung dieser Operationsmethode bei einem Kollektiv mit stark vorgeschädigter Innenohrleistung zurückzuführen.

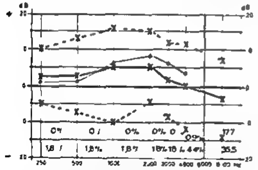


Abb. 19

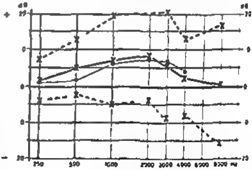


Abb. 20

Abb. 19. Fenestration (Transantrale und Kontaktmethode) 88 Fälle. x——x, Änderung der Knochenleitung zwischen dem Zeitpunkt vor und 1 Monat nach der Operation. x---x, mittlere Abweichung.

Abb. 20. Fenestration (Transantrale und Kontaktmethode) 14 Fälle. ——, Änderung der Knochenleitung zwischen dem Zeitpunkt vor der Operation und 3 Jahre nach der Operation. x---x, mittlere Abweichung.

Untersucht man das Verhalten des Innenohres bei der Fenestration im lateralen Bogengang (transantrale Methode nach Wullstein) so finden auch wir den von McConnel und Carhart beschriebenen Anstieg, den Ausgleich der sog „Carhart-Senke". Die dunnen Linien in den Abb 19 und 20 geben die Werte von McConnel und Carhart wieder. Drei Jahre nach der Operation (Abb 20) ließ sich immer noch eine deutliche Verbesserung der Knochenleitung in dem nunmehr recht klein gewordenen Kollektiv beobachten, es entsprechen sich zu diesem Zeitpunkt die von McConnel und Carhart angegebenen Werte und die von uns gemessenen fast vollstandig Eine Erklarung fur diese Innenohrreaktion können wir nicht geben, insbesondere, da auch auf dem nicht operierten Ohr ein gewisser Höranstieg erfolgt, wie fruhere Untersuchungen (Wullstein, Schmitt und H W. Naumann) ergaben Erwahnenswert erscheint die Tatsache, daß auch bei den Stapedolysen ein Anstieg der Knochenleitung (Abb. 9–16) erfolgt, wenn auch in geringerem Ausmaß als bei der Fenestration im lateralen Bogengang.

ZUSAMMENFASSUNG

Es wird eine Methode beschrieben, die die maschinelle Auswertung der audiologischen Daten, der pathologisch anatomischen Befunde bei der Operation, der chirurgischen Maßnahmen und des Heilungsverlaufes ermöglicht Als Maßstab fur den Operationserfolg einer Methode werden die arithmetischen Mittelwerte der Horverluste in Verbindung mit der Streuung bei den verschiedenen Frequenzen und Testmethoden eingefuhrt Herangezogen werden die Veranderungen der Schalleitungskomponenten, der Knochenleitung und des Sprachaudiogrammes Zur graphischen Darstellung werden je nach Aufgabenstellung entweder die Haufigkeitsverteilungskurven der gemessenen Werte oder die arithmetischen Mittel der Meßwerte verwandt

Anhand von Beispielen werden die Auswertungsmoglichkeiten der „chirurgischen Karten" erlautert und das Zusammenwirken der Verarbeitung von audiologischen, pathologisch-anatomischen und chirurgischen Daten erklart

Die typischen Veranderungen der arithmetischen Mittelwerte der Knochenleitung bei den verschiedenen Methoden der Stapedolyse und der Fenestration im lateralen Bogengang werden gezeigt Die Angaben von McConnel und Carhart uber den Anstieg der Knochenleitung bei der Fenestration im lateralen Bogengang werden bestatigt Bei den Stapedolysen wird ebenfalls eine Verbesserung der Knochenleitung, wenn auch in geringerem Ausmaß, in dem von McConnel und Carhart beschriebenen Frequenzbereich gefunden

SUMMARY

A method is described which makes possible the mechanical analysis of the audiological data, the pathologico anatomical findings at the operation, the surgical measures taken and the progress of healing As a criterion of the operative result of a method the arithmetical means of the hearing losses, combined with the dispersion in the different frequencies and test methods, are adopted The variations in the sound

conduction components, the bone conduction and the speech audiogram are used Either the frequency distribution curves of the measured values or the arithmetical means of the data, according to functional position, are used for graphical representation

The analytical potentialities of the "surgical chart" are explained by means of examples and the combined action in the processing of audiological, pathologico-anatomical and surgical data is demonstrated

The typical variations in the arithmetical mean values of bone conduction in the different methods of stapedolysis and of fenestration in the lateral semicircular canal are indicated The statements of McCONNEL and CARHART on the increase of bone conduction in fenestration in the lateral semicircular canal are confirmed In stapedolysis an improvement in bone conduction, though to a slight extent, is likewise found in the range of frequencies described by McCONNEL and CARHART

Besonderer Dank gilt Herrn cand phys Th Herbert und der Aerodynamischen Versuchsanstalt Gottingen fur die Mithilfe bei der Prufung des Auswertungsprogrammes fur den Magnettrommelrechner IBM 650 Außerdem sind wir unseren Mitarbeitern Fraulein G Knop, Fraulein H Langner und Herrn K Hamberger zu Dank verpflichtet

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Universitätsklinik H N O , Würzburg

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PHYSICAL FACTORS IN ANGULAR LOCALIZATION

Bertil Nordlund
Goteborg Sweden

From the Department of Otolaryngology (former Head Prof C A Hamberger, M D, present Head Ass Prof H E Engstrom, M D) and the Laboratory of Audiology (Head Ass Prof G Liden, M D), Sahlgrenska sjukhuset, University of Göteborg

The investigation was carried out for the purpose of clarifying the acoustic differences which arise between the ears at different azimuths Measurements of time, phase and intensity differences of the sound entering the ears of a dummy head were performed with the sound source placed at different azimuths around the head, and using the frequencies 500, 1000, 2000, 4000 and 8000 cps, with the sound source 165 cm from the head The results indicate that the time difference constitutes a linear function of azimuth between the angles of 0°–60° and between 120°–180° The same thing applies to the phase difference, if expressed in time The difference in intensity appears to be a very irregular function of azimuth and has to a great extent failed to agree with previously published findings The matter of directional hearing is discussed on the basis of physical measurements and data obtained

The most characteristic binaural function is sound localization i e the ability of a listener to report the direction and distance of a sound source This paper will deal with directional hearing only and will endeavour to explain the physical background of a listener s ability to determine the direction of a sound source disposed in a horizontal plane The capacity of being able to judge the direction of a sound in this plane depends largely upon the acoustic differences discerned by the ears when the sound waves strike the head at an oblique angle

The physical factors in binaural angular localization can be divided into three interaural differences i e (1) time (2) phase and (3) intensity The importance of these in the matter of directional hearing has been referred to in the literature and it has been found that most of the work carried out in this field has taken the form of experiments of the following nature Equipped with earphones voluntary subjects have been set to listen to acoustic stimuli including variable differences of time phase and intensity between the ears and subsequently been requested to describe their reaction to the various sound impressions At suitably selected differences the sensation of sound can take the form of an imaginary sound source i e a phantom source which exists in the listener s head only or in its close proximity In the matter of interaural time differences in such a case it has been possible to prove that a listener localizes the phantom source closest to the ear which

receives the sound first, or in other words, the listener gets the impression that the sound comes from the side. It has therefore been logical to conclude that the time difference is of importance for the directional hearing (Hornbostel & Wertheimer). Similar experiments have shown the possibility of creating an impression of a sound coming from the side through the medium of an interaural phase difference. It has thus been established that the interaural phase difference also is of importance for angular localization. The same applies to the intensity difference registered by the ears, i.e. a phantom source is imagined closer to the ear or to the side that is stimulated by the highest intensity. Experiments of this type have been described by a large number of research workers in many countries. It is rather remarkable, however, that only a few investigations have been carried out concerning the acoustic differences which in reality exist between the ears when sound waves reach the head from various angles. The authors referred to below, however, have been going into this problem.

Stewart (1911–1920) as well as Hartley & Fry (1921) have tried theoretically to calculate interaural phase and intensity ratios at various angular directions. It has been possible for these authors to perform these calculations by approximating the head to the shape of a rigid sphere with diametrically located ears. In this manner Stewart has been able to set up mathematical formulae for calculation of the ratio of phase and amplitude in the ears at various (1) frequencies, (2) angular directions, (3) distance of sound source, and (4) size of the sphere. The formulae apply in free space conditions only. Hartley & Fry have extended these calculations and demonstrate their results in a series of curves stating the phase difference and amplitude ratio at the ears in respect of various frequencies, distances and azimuths of a pin point source of pure tone. The results achieved by them tally to a great extent with those reached by Firestone, which are illustrated in Figs. 1 and 2. Firestone (1930) has completed an investigation of the phase and amplitude ratios between the ears at various angular directions and distances from the sound source, using the frequencies 256, 1024 and 1944 cps according to the following method. He made use of an artificial head of approximately normal size and fitted with microphones at the place where the eardrums would normally be located. The microphones were connected to an oscilloscope. A sound generator was then placed at various positions around the head, thus enabling the azimuth and the distance from the sound source to the head to be varied. Acoustic phase and amplitude at the location of the eardrums were pictured on the oscilloscope as a function of the distance and azimuth of the sound. As far as the phase difference is concerned, Firestone's results are shown in Fig. 1, and these nearly coincide with the phase differences theoretically computed by Hartley & Fry. Firestone's investigation of the amplitude ratio between the ears has also been described by graphs [illegible] ratio as a function of azimuth and distance from the [illegible]). This shows that, as far as the investigated frequencies [illegible] the interaural difference in intensity will be greater (*a*) the

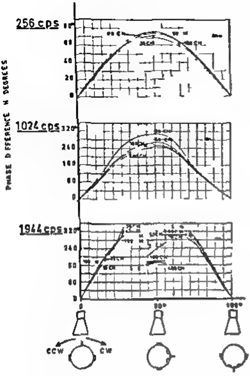

Fig 1

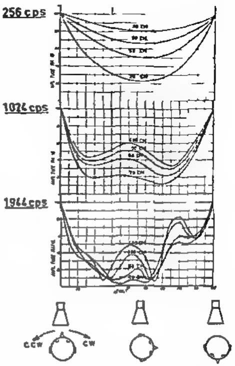

Fig 2

Fig 1 Firestone's registration of phase difference in degrees as a function of azimuth at different distances between head and sound source

Fig 2 Firestone's registration of amplitude ratio between near and far ear as a function of azimuth at different distances between head and sound source

shorter the distance between head and sound source and (*b*) the higher the frequency The graphic curves also indicate that the amplitude ratio is a very irregular function of azimuth at the frequency of 1944 cps In his concluding words Firestone states Near and below 1000 cps the values of phase difference and amplitude ratio computed (Hartley & Fry) and based on the assumption that the head is a rigid sphere in free space are in good agreement with the facts [Firestone's results] except that a better approximation can be obtained by reducing all the computed values of amplitude ratio by about 13 % At frequencies as high as 2000 cps the computed values differ from the observed values by a considerable amount In view of the complicated relation between amplitude ratio and azimuth for a pure tone of 2000 cps and the known fact that there is no phase effect at this frequency it is difficult to believe that such a tone could be localized

Sivian & White (1933) investigated the free field monaural threshold at various azimuths the intensity differences have since been computed by comparison between the threshold curves applicable for the near and the far ear In respect of the frequencies which can be compared with mine their results are shown in Fig 3

K. de Boer (1940) has set up a formula from which the interaural time difference as a function of the angular direction can be computed. The formula reads

$$t = l/c \text{ and } l = a(v + \sin v)$$

where t = the time difference, l = the difference in distance which the sound has to travel to reach the ears, c = the velocity of sound, a = half the diametrical distance between the ear orifices and v = azimuth.

F. M. Wiener (1947) investigated the difference in intensity between the ears at the azimuths 45°, 90° and 135° only. This investigation was performed by measuring the sound pressure at the entrance of meatus acusticus externus and the sound pressure on the eardrum was computed on the basis of the research work carried out by Wiener & Ross in 1946. Wiener's results are of less importance in view of the fact that the intensity difference has been recorded from three angular directions only and this will throw very little light on the matter of the intensity difference as a function of azimuth.

Feddersen, Sandel, Teas & Jefress (1955) have measured time and intensity differences at various angular directions. These recordings have been made possible by applying sound probes in the auditory canals of voluntary subjects. Azimuth has then been varied and the authors mentioned above have thus been able to measure the interaural time and interaural intensity ratio close to the eardrums at different azimuths. Their time difference recordings coincide comparatively well with the results obtained by theoretical computation of the interaural time difference when the head is regarded as a rigid sphere. Concerning the interaural intensity difference they state: "The results of the intensity measurement deviated largely from what has been commonly assumed. The greatest interaural intensity difference did not generally correspond to a source position directly to one side, and the variation in interaural intensity difference with azimuth position was markedly different for different frequencies and different subjects. The question of how subjects localize high frequency pure tones seems to be more obscure than ever." The same authors (1957) have published additional information on the subject of interaural time and intensity relations and also in this case the results coincide fairly well with the theoretically computed values of the time difference when the head is regarded as a rigid sphere. They show, however, a more rectilinear ratio between time difference and azimuth than those obtained by computation. The maximum time difference, i.e. at 90° azimuth, gave as result 0.65 ms, and at 60° azimuth 0.48 ms.

In reference to their intensity determination by means of sound probes at the eardrums, the above authors state as follows: "Obtaining repeatable measurements of interaural intensity differences proved to be very difficult. Part of this difficulty stems from the fact that the probe tube microphone is not strictly a pressure device and is sensitive to its orientation in the sound field. Also, as Wiener has shown, the depth of its entry into the ear canal affects the readings considerably, especially at high frequencies. Their

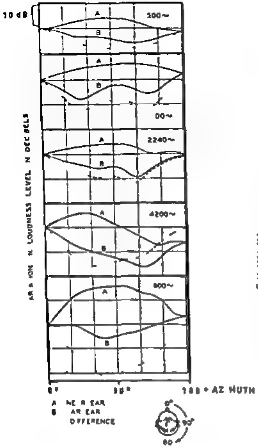

Fig 3

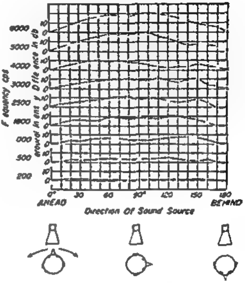

Fig 4

Fig 3 Variation in loudness level in decibels as a function of azimuth according to investigations carried out by Sivian & White

Fig 4 Interaural intensity difference in decibels as a function of azimuth from measurements obtained by Feddersen Sandel Teas & Jeffress

recorded results of the intensity difference as a function of azimuth at various frequencies are illustrated in a graph shown in Fig 4

On a model of a head Mills (1958) has measured the phase difference at various angular directions These measurements agree well with Firestone s results as well as with Hartley & Fry s calculations for the 250 and 500 cps frequencies As compared with Firestone s and Hartley & Fry s results obtained at higher frequencies and particularly at 1000 cps the phase difference as measured by Mills was found slightly smaller In the same work Mills also studied the minimum audible angle maa i e the smallest angular separation that can be detected between the source of two successive tone pulses He found that maa as a rule is smallest in the median plane but this applies strictly to frequencies below 1000 cps only In the case of higher frequencies there are several exceptions in which maa is found to be smaller at the side of the median plane The author gives no explanation of

this phenomenon, but on the basis of the following measurements it will be duly explained.

In summary it can be said regarding the interaural differences of time and phase that there is a fair unanimity as regards their magnitude and the way in which they vary with azimuth. In the matter of intensity difference as a function of azimuth considerable disagreement has been noted, as shown by the papers referred to above (Figs. 2, 3 and 4). The author has worked out a method which yields additional information about interaural differences of (1) time, (2) phase and (3) intensity as functions of azimuth. The physical basis of directional hearing will be discussed in the light of these measurements.

METHOD

A model of a head was made from a cranium and plastic material. Every effort was made to give this model the form of a true standard head. The length and diameter of the auditory canals are 27 mm and 7 mm respectively. The distance between the orifices of the auditory canals is 17 cm. The artificial head is equipped with microphones at the true location of the eardrums (condenser microphones type 4131, Bruel & Kjaer). A loudspeaker (artificial voice type 4215, Bruel & Kjaer) is used as sound source. At the investigated frequencies this loudspeaker voice produces almost spherical sound waves. The mouth of the speaker is 38 mm. The sound field was tested by rotating the speaker and the intensity at various distances from the speaker was recorded during the rotation. This proved that the sound field from the speaker within the portion in which the head was located was spherical in respect of the frequencies 500, 1000 and 2000. At the frequencies 4000 and 8000 small errors could be noted.

The model of the head as well as the loudspeaker were mounted in an anechoic chamber in the following manner. The head was placed in a corner symmetrically in relation to the walls. The shortest distance from head to wall was 120 cm, from ceiling to head 84 cm and from floor to head 120 cm. The head was mounted on a vertical motor shaft and could therefore be rotated. The motor shaft was fitted with an arm adapted to sweep along a calibrated scale divided into degrees, enabling the angular extent of the turning of the head to be recorded. The loudspeaker was set up in the corner diametrically to the head. The shortest distance from loudspeaker to wall was 80 cm and from the mouth of the loudspeaker to the vertex of the head 165 cm. The loudspeaker mouth was level with the orifices of the auditory canals and directed towards the center of the head.

Measurements of the intensity in the anechoic chamber prior to installation of the head [illegible] showed that the intensity of the sound dropped by approximately [illegible] when the distance from the loudspeaker was doubled. In the acoustical [illegible] the room may therefore be regarded as free space.

The [illegible] fitted into the head are connected across a cathode

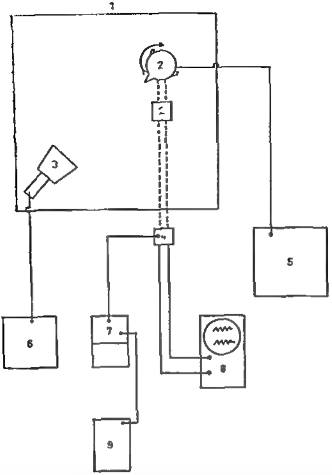

Fig 5 Assembly of the equipment for (*a*) determination of the difference in time and phase, (*b*) determination of the difference in intensity Equipment used in both (*a*) and (*b*) 1, the anechoic chamber 2, model of a head, and cathode follower mounted on a vertical motorshaft, 3, loud speaker, 4, feeding unit for cathode follower, 5, control equipment for the rotation of head 6, signal generator Equipment used in the (*a*) process only, 8, 2-channel oscilloscope Equipment used in the (*b*) process only 7, microphone amplifier with filter, 9, level recorder

follower and a battery unit in two different ways, (*a*) to a dual beam oscillo scope (type Tektronix dual beam 502), and (*b*) to a microphone amplifier with filter (type 2602, one third octave filter set, type 1609, Bruel & Kjaer), which is connected to a level recorder (type 2304, Bruel & Kjaer) The type of electronic set up specified under (*a*) was used for determining the interaural time and phase difference, whereas that described under (*b*) was employed to record the intensity difference For method of operation, see below The orientation of the equipment according to (*a*) and (*b*) is illustrated in Fig 5

Procedure of Measuring Interaural Time Difference as a Function of Azimuth

The equipment was arranged according to (*a*) The loudspeaker was stimulated by a train of electrical square waves having an impulse frequency

this phenomenon, but on the basis of the following measurements it will be duly explained.

In summary, it can be said regarding the interaural differences of time and phase that there is a fair unanimity as regards their magnitude and the way in which they vary with azimuth. In the matter of intensity difference as a function of azimuth, considerable disagreement has been noted, as shown by the papers referred to above (Figs. 2, 3 and 4.) The author has worked out a method which yields additional information about interaural differences of (1) time, (2) phase, and (3) intensity as functions of azimuth. The physical basis of directional hearing will be discussed in the light of these measurements.

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Measurements of the intensity in the anechoic chamber prior to installation of the head showed that the intensity of the sound dropped by approximately [illegible] when the distance from the loudspeaker was doubled. In the acoustical sense [illegible] the [illegible] room may therefore be regarded as free space.

The [illegible] phones fitted into the head are connected across a cathode

TABLE 1 *Result of determination of difference in time at various azimuths The model of the head has been rotated clockwise as well as counter clockwise*

Azimuth	Time difference in ms	Azimuth	Time difference in ms	Azimuth	Time difference in ms	Azimuth	Time difference in ms
0 0	0 00	30 7	0 28	65 0	0 58		
1 1	0 02	31 9	0 [illegible]9	6[illegible] 8	0 6[illegible]	1[illegible]	[illegible]
3 3	0 04	35 2	0 32	69	0 6[illegible]		
5 0	0 05	35 5	0 32	[illegible]1 [illegible]	0 64	1[illegible]	[illegible]3
5 3	0 05	36 0	0 33	[illegible]1	[illegible]	1[illegible]	0 [illegible]
5 6	0 06	37 2	0 33	[illegible] 5	0 67	1[illegible]	0 [illegible]
7 6	0 07	40 9	0 37	[illegible]	0 6[illegible]	13[illegible]	[illegible]
8 7	0 08	41 4	0 37	[illegible] 0	0 [illegible]9	1[illegible]	
9 1	0 09	42 1	0 37	[illegible] 5	0 [illegible]1	13[illegible]	[illegible]
11 [illegible]	0 11	43 5	0 37	8[illegible] 9	0 [illegible]2	14[illegible]	[illegible]
12 0	0 11	4[illegible] 0	0 40	8[illegible] 5	0 [illegible]2	14[illegible]	
1[illegible] 2	0 12	46 7	0 40	89 8	0 [illegible]2	14[illegible]	[illegible]
14 5	0 14	48 0	0 43	93 8	0 [illegible]2	1[illegible] 3	
16 3	0 15	50 6	0 43	96 2	0 [illegible]	1[illegible] 5	[illegible]
17 0	0 16	52 2	0 45	96 5	0 73	1[illegible] 9	0 19
19 8	0 18	52 6	0 46	99 0	0 [illegible]2	161 8	0 17
20 9	0 19	56 2	0 50	100 8	0 69	1[illegible]	0 14
2[illegible] 6	0 21	57 9	0 52	103 9	0 [illegible]4	1[illegible] 9	0 13
22 9	0 21	58 1	0 52	105 0	0 67	171 0	0 0[illegible]
24 9	0 23	59 4	0 54	106 0	0 64	1[illegible]2 [illegible]	0 07
25 2	0 [illegible]3	61 2	0 54	108 0	0 65	177 1	0 03
28 3	0 26	62 4	0 56	110 0	0 6[illegible]	180 0	0 00
29 6	0 27	64 8	0 59	111 0	0 59		

as a function of azimuth is shown in Fig 6 and 7 In these illustrations the head has been rotated counter clockwise in 10° steps from 0 to 70° and the oscilloscope is arranged in such a manner that 1 square horizontally corresponds to 0 1 ms and 1 square vertically to 10 mV The upper curve represents the left ear and the lower the right ear When the head is rotated 10° counter clockwise the sound will reach the right ear at an earlier moment whilst being delayed in the left ear This relation increases with additional turning of the head The horizontal distance between two corresponding points on the curved lines from left and right ear respectively represents the interaural time differences illustrated in the figure by the continuous horizontal line At 10°, the interaural time difference was found to be [illegible] 1 ms at 20° 0 18 ms etc

The most important sources of error are as follows Erroneous reading of points on the oscilloscope screen due to the thickness of the curve and to the difficulty in determining corresponding points Within the range of the angles 0–60 and 120–180 this reading error has been estimated to be less than 0 02 ms and less than 0 05 ms between the angles 60–120 The error tolerance of

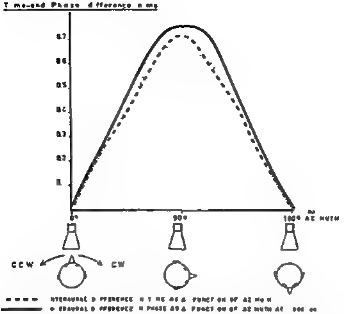

Fig 8 Result of the determination of the difference in time as a function of azimuth (dotted curve line) This coincides with the difference in phase as expressed in time for the frequencies 2000, 4000 and 8000 cps The drawn graph line represents the difference in phase for 1000 cps and falls within the limits of error as established by Firestone

the oscilloscope was stated to be ±1 ‰, which would correspond to an error of up to 0 01 ms in conjunction with the time difference of longest duration

The angular turning movement of the head could be established with an accuracy of ±0 25° In consideration of other errors, this accuracy can be regarded as quite sufficient for the purpose

The model of the head is not exactly symmetrical It has, however, been rotated both clockwise and counter clockwise in this measuring procedure, and there is no significant difference between the results The asymmetry of the head is therefore of no account Obviously, however, the time difference may vary slightly in different subjects, depending upon variations in the distance between the ears, shape of the face and concha auriculae, etc

As previously mentioned, the model of the head used in these experiments has been given the shape of a head of standard form The results can therefore be considered as representative in respect of the time differences which actually exist between normal ears

Results

The result of the determination of the interaural time difference with the aid of clicks is shown in Table 1, and illustrated in Fig 8, which shows the time difference as a function of azimuth when the distance between head and sound source was 165 cm

1 A linear relation exists between the time difference and azimuth within the sec [illegible] and 120°–180° The duration of the time difference is thus [illegible] directly proportional to the angular displacement of the sound

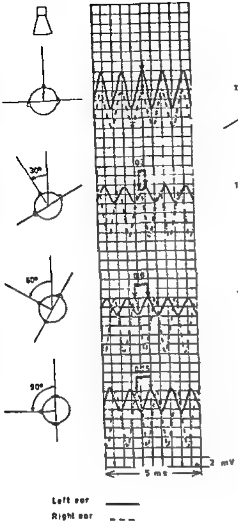

Fig 9

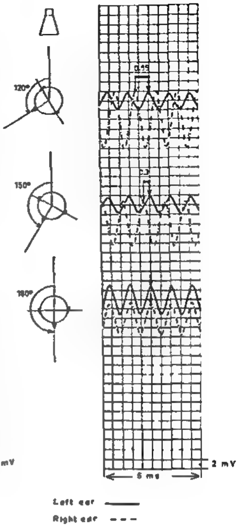

Fig 10

Figs 9 and 10 Recording of the difference in phase as expressed in time at various azimuths (see text)

2 The duration of the time difference is maximum about 0 7 ms at 90° azimuth, i e when the sound waves arrive straight from the side

Procedure of Measuring Interaural Phase Difference

The interaural phase difference can be expressed in time, in which case it can be regarded as time difference of pure tones Interaural phase difference, therefore, can be regarded as a special feature of time difference and can consequently be measured in the same manner as the interaural time difference simply by letting the speaker voice be stimulated by pure tones using the frequencies 1000 2000 4000 and 8000 cps

Expressed in time the phase difference can be read from the screen of the

oscilloscope by measuring the horizontal distance between two corresponding points on the curve lines representing left and right ear respectively. This is demonstrated in Figs. 9 and 10, where the speaker voice is stimulated by a frequency of 1000 cps, and the head is rotated counter clockwise in 30° steps (1 square horizontal corresponds to 0.5 ms and 1 square vertical to 2 mV).

The sources of error referred to in connection with the measuring of the interaural time difference apply also in the main as far as determination of the interaural phase difference is concerned. At low frequencies, however, it is impossible to measure the phase difference with the same accuracy as the time difference. The difficulty in obtaining quite accurate measurements is due to the fact that the maximum and minimum curvature produced on the graph will be greatly flattened at low frequencies, and it is therefore almost impossible to measure the distance between two corresponding points on the curves.

Results

The result of the measuring of the interaural phase difference as a function of azimuth at the distance 165 cm between head and the sound source is shown in Fig. 8.

1. At the frequencies 2000, 4000 and 8000, a phase displacement of an entire wave length resulted, i.e. the right and left ears were again in phase when the azimuths measured 57°, 28° and 14° respectively.
2. At the frequencies 2000, 4000 and 8000, the phase difference as a function of azimuth coincides with the interaural time difference curve for clicks at azimuths less than 57°, 28° and 14° respectively.
3. At frequencies below 1400 cps the phase difference constitutes almost a linear function of azimuth for angles of 0–60° and 120°–180°.

Procedure of Measuring Interaural Intensity Difference

*The equipment was arranged according to (b) in Fig. 5, i.e. with the micro*phones of the head model connected to a level recorder across a cathode follower battery unit and a microphone amplifier with filter. The speaker was set up 165 cm from the model of the head, which latter was then rotated to the extent necessary to level out the intensity difference between the ears. This position was marked 0° and the zero position thus established was found to coincide with the geometrical zero setting, i.e. the nose of the artificial head was pointing directly towards the sound source. The following frequencies were used: 500, 1000, 2000, 4000 and 8000 cps. The speaker was stimulated by a pure tone. The model of the head was then made to rotate at constant speed from z[illegible] to 180°, whilst the level recorder registered the int[illegible] f[illegible]m one of the [illegible]rs selectively with regard to frequency. A process of [illegible] recording [illegible]s thus carried out during the rotational movement [illegible] the intensity difference as a function of azimuth thus constitutes

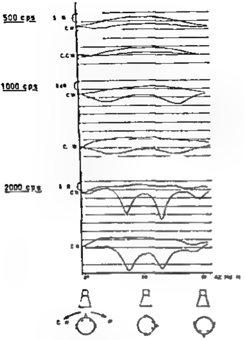

Fig 11

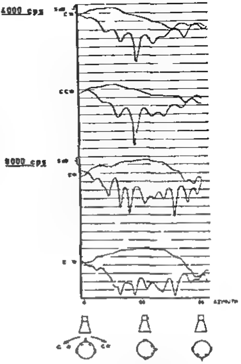

Fig 12

Fig 11 Registration of the intensity at place of the eardrums as a function of azimuth at the frequencies 500 1000 and 2000 cps with the distance 165 cm between head and the sound source

Fig 12 Registration of the intensity at the place of the eardrums as a function of azimuth at the frequencies 4000 and 8000 cps with the distance 165 cm between head and the sound source

the difference between the curve lines on the graph representing left and right ear respectively

The speaker will not produce totally spherical sound waves at the frequencies of 4000 and 8000 cps The error introduced however amounts to about 1 db only and in view of the fact that the variations of intensity at variable angular directions at these frequencies are very much more extensive the effect of this slight error on the result is insignificant

The model of the head is not exactly symmetrical and it has consequently been rotated in both clockwise and counter clockwise directions for the purpose of establishing whether the asymmetric form has any effect on the result Every effort has been made to produce a model of a head acoustically identical with that of a human being

Results

The result of the recordings is shown in Figs 11 and 12

1 Interaural intensity difference increases generally with rising frequency

2 Intensity minima arise in the far ear when the angular direction and the frequency have been so adjusted that the sound travelling mainly in front of and the sound passing principally behind the model of the head is displaced

to the extent of half a wave length in relation to each other on the arrival at the orifice of the auditory canal in the far ear

3 At the frequencies 4000 and 8000 cps the intensity is significantly greater in both ears when the sound comes from straight ahead than when it arrives from directly behind but not in the case of other frequencies employed

4 The results of the measurements on clockwise and counter clockwise rotation show slight dissimilarities as is evident from Figs 11 and 12 The intensity difference thus appears to vary as a result of slight differences in the experimental set up and conditions This is particularly noticeable in the case of high frequencies

5 The greatest intensity difference does not occur at 90° azimuth with the use of any of the frequencies which have been made subject to investigation

DISCUSSION

Time difference

According to the results illustrated in Fig [illegible] a definite time difference corresponds to two angles between 0 and 180° As a consequence of the last mentioned fact difference in time cannot furnish any clues to the localisation of sound from ahead or behind This has been proved in practice by Stevens & Newman (1936) as well as Klensch (1949) The inability to separate sounds from ahead or behind with the aid of the time difference (phase difference) is overcome if the subject on trial is given the facility of turning his head Such an action will divulge which ear will approach or recede from the sound source and thus provide information as to whether the sound comes from ahead or behind From the point of view of directional hearing however, the most interesting range is that from 0 to 90° in this case a definite angle of direction corresponds to a definite time difference Physically the possibility thus exists of localizing a sound by means of the difference in time within this range Directional hearing is therefore possible provided a human being is able to discriminate and time these slight interaural differences and convert them into an impression of hearing the sound from the side

von Békésy (1930) has stated that the apparent direction of the image of a dichotic click is proportional to the interaural time difference Therefore a physiological discrimination does exist which is capable of determining the magnitude of an interaural time difference and converting this into the impression of a sound from the side The angle of lateralisation will be directly proportional to the duration of the time difference This physiologically established direct proportionality agrees fairly well with the physical l[illegible] relation between time difference and the angle within the range zero t[illegible] Fig 8) There are thus both physiological and physical prerequisites f[illegible] [illegible]lization of sound of a click character with the aid of the time [illegible] the ears von Békésy (1930) and Campbell (1959) have me[illegible] the threshold of discrimination of time difference variation as a

function of the absolute difference in time between the ears. von Békésy found that the threshold remained constant at 0.019 ms when the absolute time difference between the ears increased from zero to 0.6 ms. Campbell found that the threshold increased from 0.012 to 0.021 ms when the absolute time difference between the ears increased from zero to 0.6 ms. The discrimination of slight variations in the difference in time is thus very good and corresponds to approximately 2° angular displacement of a sound source according to Fig. 8. There are consequently physiological as well as physical pre-requisites for discrimination of a variation in the angle of a sound of click character with the aid of the time difference between the ears.

Phase difference

Zwislocki & Feldman (1956), Klump (1956) and Mills (1958) have shown that the ear is sensitive to displacements in phase between the ears at frequencies below about 1400 cps only. The threshold of the smallest perceptible phase displacement varies with frequency. The smallest phase difference expressed in time is approximately 0.013 ms at the frequency of 800 cps. The threshold then increases at lower frequencies and at 300 cps it has a value of about 0.025 ms. At frequencies above 800 the threshold for phase discrimination also increases considerably, finally to reach an upper frequency limit for phase discrimination at about 1400 cps.

Hartley & Fry (1921) have shown that the apparent direction of the image of a dichotic tone in the low frequency range is proportional to the interaural difference in time up to a limit corresponding to 180° of phase. Consequently there does exist a physiological ability to discriminate an interaural phase difference at the above mentioned frequencies, and to convert this into an impression of sound from the side. It is evident from the determination of the phase difference (Fig. 8) that a definite phase difference corresponds to a definite angle within the range zero to 90°, and that there is a comparatively linear ratio between the phase difference as expressed in time and azimuth. In the physical sense it should therefore be possible to localize pure tones below 1400 cps by means of the phase difference within the range ±90°. The threshold of the physiological discrimination of the phase difference in the median plane corresponds, according to Fig. 8, to about 2° angular displacement of a sound source. Mills (1958) has demonstrated that the threshold for a change of interaural difference in phase is a positive exponential function of the absolute interaural difference in phase. This would imply that the ability to localize pure tones below 1400 cps would deteriorate at the side of the median plane. This has not, however, yet been fully studied.

Intensity difference

Pure tones of a frequency of more than 1400 cps can be localized only with the aid of the intensity difference between the ears. This is evidenced by the fact that the ears are unable to register any interaural phase difference at these frequencies (see above). In the case of pure tones above 1400 cps the

intensity difference between the ears therefore becomes the only physical prerequisite for directional hearing. From the determination of the intensity difference (Figs. 11 and 12) it has been found that this difference constitutes a very irregular function of the angle when applied to higher frequencies. Firestone (1930), who measured the phase and amplitude ratio between the ears at various audible angles, has shown that an extinguishing effect may arise in the far ear when there is a phase displacement of half a wave length between the sound passing substantially in front of the head, and that passing mainly behind same, on reaching the far ear. This fact can be studied in Figs. 11 and 12. There is no "extinguishing effect" at the frequency of 500. This is due to the fact that, in the case of this long wave length, a phase displacement of half a wave length between the sound passing substantially in front of the head and that passing mainly behind cannot occur upon impinging on the far ear. The phenomenon, on the other hand, will occur at the frequency of 1000 cps and over. As a natural consequence of the shorter wave length, it can be said that the higher the frequency, the greater will be the number of minima. It should be noted that this circumstance may easily be overlooked unless continuous registration of the intensity is being carried out during the rotation of the head. The phase alters very rapidly upon a slight change of the angular direction in these minima. This is acounted for by the fact that in one case the phase is principally influenced by the sound passing in front of the head, whereas, in the case of a slight change in the angular direction, the phase is determined mainly by the sound which passes behind the head. Firestone shows (Fig. 2) that the intensity difference follows the same pattern at different distances between head and sound source and that it is only a slight difference in the pattern at the distances 1 m and 4 m. The distance 165 cm, which is the length I have investigated, will therefore form a fairly true picture of the condition prevailing even at longer distances.

The measuring operations have shown that the same interaural intensity difference can be registered at a plurality of angular directions of the sound and this rule applies to an even greater extent in the case of high frequencies (Figs. 11 and 12). This obviously gives rise to confusion in localization experiments of pure tones of high frequency, and the physical prerequisite for localization of pure high frequency tones, therefore, is confined to the median plane, i.e. the head must be movable so that the direction of the sound from its source can be traced. There can be no confusion in such a case because the intensity will then be of identical volume in both ears only at the azimuths 0 and 180°. Localization of sound from in front and behind constitutes no problem with a movable head, since a turning movement of the head will reveal which one of the ears will approach or recede from the s[illegible] source. Mills (1958) has shown that the minimum audible angle at [illegible] can be smaller at the side of the median plane. This is no [illegible] theoretically expected according to my investigation [illegible] intensity difference between the ears at certain angles at the side

of the median plane will alter very rapidly as a consequence of a slight azimuth change, as shown in Figs. 11 and 12.

Timbre

The ability of monaural localization of sound depends on the change in the timbre of the sound arising at various audible angles. The relation between high and low frequency tones differs and depends on the structural form of the concha auriculae as well as the sound wall effect of the head. Good hearing and a composite sound including tones of high frequency are therefore required for the creation of this effect. This will also give us perception of the localization of sound from behind and ahead, which neither the difference in time, phase nor intensity will do if the head is fixed.

The timbre of sound will be further discussed in a future paper which will also include a more detailed description of the artificial head used in the experiment.

Sound localization test

Supported by the results published above, a complete investigation of the ability of sound localization should be based on an investigation of the interaural time, phase and intensity discrimination. This can be accomplished by the use of a buzzing sound, a tone of low frequency and one of high frequency. The ability to localize these will then in the main furnish an expression of the discrimination of the difference in time and phase respectively, whereas the high frequency tone will provide a measure of the discrimination of intensity differences. In the case of the two first mentioned examinations the investigation can be carried out with fixed head and thus provide a test of the ability to localize sounds at the side of the median plane. As previously mentioned, however, on the other hand the tone of high frequency can be localized in the median plane only, and the pre-requisite of success in such a case is a movable head. The examination could be further complemented by the introduction of a buzz of high frequency also for the purpose of judging the ability to discriminate timbre. Such a procedure however will also produce a measure of the time and intensity discrimination, and can therefore not be expected to reveal any further information. An investigation of the sound localization ability, based on the procedure outlined above, will be presented in a coming paper.

ZUSAMMENFASSUNG

Der Zweck dieser Untersuchung ist, Klarheit in die akustischen Unterschiede zwischen den beiden Ohren bei verschiedenen Azimuthen zu bringen. Die Messungen der Zeit-, Phasen- und Intensitätsunterschiede des Schalles, der in die Ohren des künstlichen Kopfes dringt, mit der Schallquelle an verschiedenen Azimuthen um den Kopf herum bei einem Abstand von 165 cm, wurde mit den Frequenzen von 500, 1000, 2000, 4000 und 8000 Hz ausgeführt. Die Resultate zeigen, dass der Zeitunter

schied eine gradlinige Funktion des Azimuthes in den Winkelbereichen 0–60° und 120°–180° ist. Das Gleiche gilt für den Phasenunterschied, ausgedrückt in Zeit. Der Intensitätsunterschied erweist sich als eine unregelmässige Funktion des Azimuthes und stimmt weitgehend sehr schlecht mit früheren Veröffentlichungen überein. Die Frage des Richtungshörens wird auf der Basis der physikalischen Messungen diskutiert.

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Sahlgrenska Sjukhuset, University of Goteborg

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ANNOUNCEMENT

ELECTRICAL ANALOG OF THE HUMAN EAR

The Applied Research Laboratory of the University of Arizona announces that the Sensory Systems Group has successfully completed the construction of an electrical analog of the human ear. This analog ear directly models the outer, middle, and inner ear. The cochlea is represented by the electrical equivalent of 36 segments, each representing one millimeter along the basilar membrane.

The complete pattern along the model cochlea is sampled at 40 times per second by a mercury jet commutator and displayed on an oscilloscope. The output of the cochlea is the modeled neural equivalent of either amplitude displacement or velocity of the basilar membrane. The conversion of the response for each segment of the *cochlea to a neural equivalent of either amplitude or velocity enables the analog* to model the subjective attribute of loudness. The device operates in real time and has a frequency response from 20 cps to 20 kcps. The analog ear will be employed in studies of speech analysis and the interpretation of psycho-physical phenomena in audition. The outcome of these initial studies will be used in the study and development of speech recognition and communication systems. It is anticipated that the resulting techniques will ultimately yield a speech bandwidth compression to the order of 10 cps, which is essentially language-independent.

The interdisciplinary Sensory Systems Group, under the direction of Dr. J. L. Stewart, Professor of Electrical Engineering, consists of E. Glaesser and W. I. Caldwell, electrical engineers, R. M. Brooks, applied psychologist, and K. H. Dimmick, audiologist.

BOOK REVIEW

SCHUCHARDT, KARL. *Fortschritte der Kiefer- und Gesichts-Chirurgie*, Band VII. Georg Thieme Verlag, Stuttgart.

This volume contains the greater part of the lectures and contributions to the discussions at the Tenth Congress of the Deutschen Gesellschaft fur Kiefer- und Gesicht-Chirurgie, which was held in September 1960 in Salzburg.

The principal theme of this congress was the aesthetic factors in maxillofacial surgery. Practically all the lectures deal with plastic facial operations. For the patient the cosmetic results of these operations are usually more important than the functional ones. This volume, like earlier ones, is printed on a paper which does full justice to the abundant pictorial material. The editing and the typography are both exemplary. This book is without doubt of great value for all doctors interested in plastic surgery.

Bertel Ivstam

HYPERNEPHROMETASTASIS IN THE LARYNX

Radical Extirpation before Diagnosis of Primary Tumour

M Bergstedt and G Herberts
Umea Sweden

From the Department of Otolaryngology (Head Prof G Herberts) Royal Medical School Umeå

It has long been known that hypernephroma can metastise to practically any tissue in the body Its predilection is for the tissues of the lung lymphatic nodules bone tissue and the liver in that order (Lubarsch) The metastases can often be solitary and are sometimes not noticed until many years after operation for the primary tumour The spreading mechanism would seem above all to be hematogenic Surgery directed against solitary metastasis would therefore appear to be indicated By way of a curiosity Beer & Mann have reported a case of spontaneous disappearance of obvious lung metastasis after nephrectomy It seems to be more seldom however that metastases from hypernephroma are diagnosed and treated before the primary tumour This was so in the following case which is also of interest from the otological point of view, since the metastasis which led to the diagnosis was localised in the larynx and the patient was affected with heavy bleeding in the throat

Case report

G J journ no 76/1958 ASL 60 year old woman inmate of a mental institution from the age of 30 for schizophrenia Her illness was moderate and she was calm and easily handled throughout the period Eighteen years ago she was operated on for ca solidum mammae dx with ablatio mam excer axillae with evacuation of the auxiliary lymph glands She returned to normal health after the operation and did not thereafter show signs of relapse of ca mam She had not shown signs of any gastro intestinal symptom up until the current affection (around New Year 1957 58) when she was transferred to the medical clinic with melaena haemoptysis and vomiting of blood for the previous few days The patient who had bled considerably had on arrival at the medical clinic Hb 51% and non protein nitrogen (N P N) 73 mg% the urine showed nothing pathological Blood pressure was 230 110 S R –17 mm Positive Weber She had a Cushing s disease appearance with corpulence a full moon face beard and hypertonia E N T examination on 6 1 58 showed a blue–red tumour at least the size of a cherry in the left part of the hypopharynx obscuring the entrance to the larynx the patient was then transferred to the ear clinic

Her general condition was good though she spoke somewhat thickly

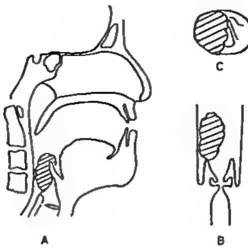

Fig. 1. Schematic picture illustrating the location of the metastatic tumour of the hypopharynx (hypernephroma metastasis). A. Sagittal section of the head. Tumour marked with oblique lines. B. Frontal section through larynx and hypopharynx. The tumour protruding from the plica aryepiglottica. C. View from above. The left vocal cord is seen partly.

On laryngoscopy there was observed in the left part of the hypopharynx an upward growing tumour, slightly lobed and partly ulcerated. The right vocal cord was completely free and normal, the left could only be seen with difficulty and likewise seemed normal. The tumour appeared to arise from the left portion of the entrance to the larynx and constituted no hindrance to breathing at rest. It was not pendulous (see Fig. 1).

A preoperative X-ray examination could not be considered because of the heavy bleeding and risk to aspiration. Tracheotomy was therefore carried out. Inspection of the trachea and larynx from the stoma revealed nothing of note. On the following day extirpation of the tumour by means of direct laryngoscopy was carried out under narcosis through a tracheal cannula (Herberts). The tumour was found to be double the size of a walnut and grew out from a broad base in the left plica aryepiglottica. Its cranial part formed an ulcerated bundle the size of the end of a finger (see above). In spite of initial heavy bleeding the tumour was able to be sliced off in bits down to its base. Here there appeared healthy, excoriated tissue surface of normal structure and bleeding ceased. Entry to oesophagus was normal. Tube in ventricle. The postoperative course was smooth. Decannulation after two weeks. Biopsy diagnosis showed suspected hypernephroma. Subsequent to operation the patient had mild anaemia of secondary type, blood sedimentation rate 40–50 mm/hour, urine examination was normal. N.P.N. 3[illegible] and 36 mg% respectively. Intravenous urography revealed expansive process in left kidney. Patient was transferred to general surgery clinic where he was operated on (nephrectomia sin. + ectomia gland. suprarenalis sin.).

There was a fist-sized tumour in the kidney and two metastases in the left suprarenal gland. Biopsy diagnosis showed the same picture as in the

Fig 2

Fig 3

Fig 4

Fig 5

Fig 2 Hypernephrometastasis in the larynx Superficial section with necros

Fig 3 Section from more inferior portion of same tumour showing islets of tumorous ingrowth

Fig 4 Larynx metastasis Section from solid part of tumour

Fig 5 Hypernephrometastasis in suprarenal Superior portion Normal suprarenal tissue is seen below

larynx tumour The post operative course was free from complication X ray of skull and skeleton and lungs showed no sign of metastasis Larynx and hypopharynx X ray was normal At a check 2½ years after operation the patient was found to be clinically healed without sign of further metastasis Laryngoscopy gave a normal picture Patient's physical state unchanged

DISCUSSION

It would appear from the literature that metastasis of hypernephroma in the larynx is extremely uncommon Tamura & Nakamoto report a case of a

small tumour metastasis in the anterior commissure 4 months after nephrectomy for hypernephroma. Menzel writes of a case of metastasis to the right false vocal cord. Kuster reports on cases of metastasis to the wind pipe and Lauber on one case to the pharynx. Recently Eneroth, Martensson & Thulin have written on a case of hypernephrometastasis in the nose.

As could be expected, bleeding is a cardinal symptom of the highly vascular hypernephrometastasis in the air passage. In the case discussed above there was no clinical suspicion of kidney tumour, for which reason the biopsy was decisive. It is of interest that the patient showed a Cushing-like picture (cf. metastases of left suprarenal) and that she had been operated on 18 years previously for mammary tumour. This demonstrates the known situation with repeated affections of dissimilar malignant tumours. It is possible that the patient's psychic illness masked the other symptoms in the general picture of her affection—the Cushing syndrome and kidney tumour. It is, however, probable that in view of the lack of the common objective symptoms the hypernephroma would not have been diagnosed here, even if she had been psychically normal.

From a general surgical point of view the case illustrates the significance of surgical handling even of metastases from hypernephroma, and especially in any case where it is diagnosed as solitary. From an otological point of view the case shows the possibilities of endoscopic treatment and radical removal of tumours which, because of their localisation and tendency to bleeding, are accompanied by considerable risk to aspiration.

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Royal Medical School, Lund, Sweden

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COCHLEAR BLOOD FLOW IN ACOUSTIC TRAUMA[1]

H. B. Perlman and Robert Kimura
Chicago, Ill., U.S.A.

From the Section of Otolaryngology (Head: J. R. Lindsay), University of Chicago

Some normal values of cochlear blood flow rate, cochlear function (microphonic response to 2?7 cycles at 90 db), carotid pulse pressure and heart rate are presented along with changes due to excessive acoustic stimulation. The relation of cochlear blood flow to the oxygen demands of the cochlea is considered.

Homeostatic mechanisms that could adjust regional blood flow to regional changes in metabolism of the nervous system has been the object of much investigation and speculation. It is generally held that a rise in activity of functionally discrete areas in the nervous system as well as in other organs is accompanied by an increase in regional blood flow. The evidence for this is based on a wide variety of experimental observations usually of an indirect nature, i.e. rise in temperature, PCO_2 and PO_2 in the strychninized occipital lobe on photic stimulation of the retina (Meyer & Gotoh 1960). Recent experiments on the cochlea also using indirect methods (oxygen and hydrogen electrodes) have been concerned with homeostatic mechanisms relating acoustic stimulation to permeability and blood flow in the stria vascularis (Misrahy *et al.* 1958). Among the explanations of observed effects, i.e. drop in oxygen availability with strong acoustic stimuli and direct observations on vessels of the hamster cheek pouch exposed to very intense sound, no change or a reduced blood flow in the strial vessels with strong acoustic stimulation was postulated, leading to a reduction in the ratio between oxygen supply and oxygen demand of the cochlea. Direct examination of the cerebral or cochlear capillary blood flow during appropriate stimulation has not been reported. Large vessels in the cortex have been observed to dilate with seizures (Meyer & Portnoy 1959). Direct inspection of capillary blood flow in the brain is difficult because of the anatomical arrangement by which only the larger vessels are visible on the surface of the cortex. On the other hand, blood flow in the capillaries of the stria vascularis and spiral ligament can be examined. Some relations of altered blood flow in these capillaries to acoustic function have been reported by us previously, i.e. occlusion of the in-

[1] This work was aided in part by Grant B2 [illegible]9 (C8) from the United States Public Health Service and the Douglas Smith Foundation.

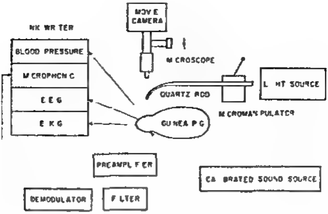

FIG. 1. Block diagram of equipment used for simultaneous recording of cochlear blood flow, cochlear microphonic, electroencephalogram, electrocardiogram and blood pressure in the guinea pig.

ferior cochlear vein (1957), permanent and temporary obstruction of the internal auditory artery (1959), and general hypothermia (1959).

The effect of auditory stimulation on blood flow in the strial vessels of the normal cochlea is reported in this communication.

METHOD

The method for fenestrating and transilluminating the apical turn of the guinea pig cochlea for moving picture recording of blood flow in the exposed vessels of the stria and spiral ligament has been previously described by us (1955). An orderly movement of white blood cells along these vessels permits measurement of flow velocity of the blood column and thus has already been used to study blood flow changes during hypothermia. The effect of strong acoustic stimulation through an intact conducting mechanism upon the fenestration site, particularly when using low frequencies, i.e. 277 cycles, necessitated some modifications of the method, since the vessels and other soft tissue were set in acoustic vibration. It was therefore necessary to seal the fenestration site or to thin the cochlea capsule so that blood flow could be observed and recorded through the capsule bone or the acoustically sealed fenestrum. Acoustic sealing of the fenestration site covered with glass was accomplished by floating the glass on high viscosity silicone and surrounding the edges with Eastman 910 cement. In addition, it was necessary in some cases to apply pressure on the glass by means of a slotted probe mounted in a micromanipulator. Most satisfactory results were obtained, however, by observing the vessels through the intact, carefully thinned otic capsule. Unphysiological vibration of the stria and spiral ligament was thus eliminated. Adequately prepared fields did not reveal any vibration with the most intense acoustic stimulation generated by our equipment, 153 db at 277 cycles. To record the microphonic response of the cochlea, electrodes (20 μ in diameter) were placed in the scala tympani and scala vestibuli of the

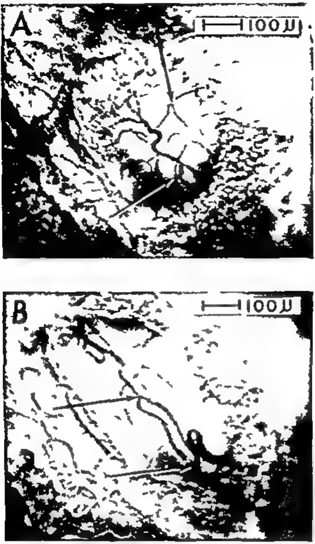

FIG. 2. Representative vascular beds of the stria and spiral ligament exposed by fenestrating the apical turn of the guinea pig cochlea for transillumination and moving picture recording. Arrows indicate typical vessel segment through which white blood cell movement is timed: an arteriovenous arcade in A and strial capillary in *B*.

third turn in the coil just proximal to the fenestra. The microphonic response for short pulses after amplification and rectification was recorded on an ink writer[1] simultaneously with the E.E.G., E.K.G. and pulse pressure. Through the microscope at magnifications between 100–165 blood flow was recorded in colored moving pictures at 32 frames per second before, during and after exposure to low and high frequency sounds of various intensities. Velocity

[1] We wish to thank Dr. Cesar Fernandez and Mr. Roger Anderson for advice about the microphonic recording.

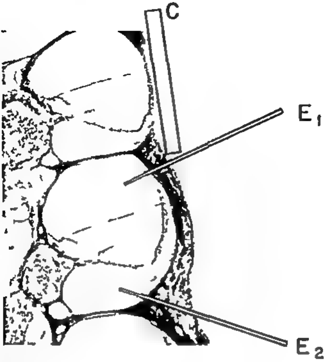

Fig. 3. Photomicrograph of the third and fourth turns of the cochlea indicating the relation of the intracochlear electrodes for microphonic recordings (E_1 and E_2) to the cochlear fenestrum covered by glass (C) for blood flow recording.

was measured by projecting the film on the screen and counting the number of frames required for moving a given white blood cell through a measured distance along a blood vessel. Distance travelled and diameter of vessels were measured with the aid of a projected micrometer scale photographed with the same optics. Many animals (60 of 74 used in this experiment) were then perfused within an hour for subsequent histological examination of the cochlea. A block diagram of the experimental arrangement is seen in Fig. 1. *Details of the exposed vascular bed and its relation to the rest of the cochlea* is illustrated in Fig. 2.

The arrangement of the electrodes in relation to the fenestration site is illustrated in Fig. 3.

FINDINGS

There is an orderly stable movement of blood in all the functional units of this terminal vascular bed under normal conditions. The diameter of the vessels is also stable. Furthermore there are no vessels that close off and no new vessels appearing in the exposed field even with such powerful vasomotor stimuli as anoxia and asphyxia. All of the vessels that are normally present in this area as demonstrated by perfusion methods and microscopic sections are visible at the site of fenestration.

TABLE 1 *Velocity of blood flow and vessel diameter at site of fenestration*

Sp, spiral ligament vessel, St, capillary of the stria vascularis, Ra radiating arteriole Cv, collecting venule The length of the vascular segment used and traverse time through it is also listed

Animal number	Velocity μ/sec	Distance μ	Time sec	Diameter μ
1	251 Sp	108	0.43	5
	65 St	78	1.20	9
2	234 Sp	248	1.06	6
3	111 Sp	139	1.25	6
4	353 Ra	190	0.54	10
[illegible]	229 Sp	124	0.54	7
	94 St	238	2.53	9
[illegible]	384 Ra	207	0.54	[illegible]
7	140 Sp	133	0.95	6
8	273 Sp	148	0.54	8
	78 St	84	1.08	9
9	249 Sp	114	0.46	5
	149 St	137	0.92	8
10	196 St	134	0.68	14
11	60 St	129	2.15	8
12	129 St	147	1.14	14
13	134 St	113	0.84	8
14	123 St	190	1.55	14
15	306 Sp	122	0.40	7
	362 Cv	102	0.28	10
16	161 St	176	1.09	15
17	99 St	148	1.49	9

TABLE 2 *Representative normal values for cochlear blood flow rate associated with microphonic, carotid pressure and heart rate*

Animal number	Velocity μ/sec	Microphonic[a] μv	Pulse pressure mm Hg	Heart rate min
1	95 St	1140	—	288
2	356 Ra St	1250	—	288
3	250 Ra St	670	60 32	324
4	262 Ra St	1210	55 25	312
5	141 St	1000	48 28	276
[illegible]	176 St	1200	60 31	264
7	184 St	1220	—	—
8	112 St	1100	57 28	294
9	235 Ra–St	1080	66 38	294
10	65 St	1180	50 28	300
11	153 St	1190	67 42	324
12	205 St	1250	50 30	240
13	124 St	1120	60 30	318
14	97 St	1220	58 35	300

[a] Microphonic response to 277 cycles at 90 db

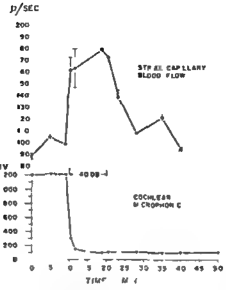

Fig. 4. Chart showing values in micra per second for flow rate in a segment of a strial capillary recorded through the thinned otic capsule and the simultaneous microphonic response to a 277 cycle tone at 90 DB before and after exposure to a 277 cycle tone at 140 DB for 10 minutes.

Note the almost immediate rise in flow rate sustained through the period of overstimulation and then the return towards the pre exposed value within 10–20 minutes after cessation of the traumatizing stimulus. The microphonic response to the 90 DB signal is promptly and almost completely and permanently abolished by this stimulus. Photomicrograph of the stria and end organ in this animal is seen in Fig. 6 B.

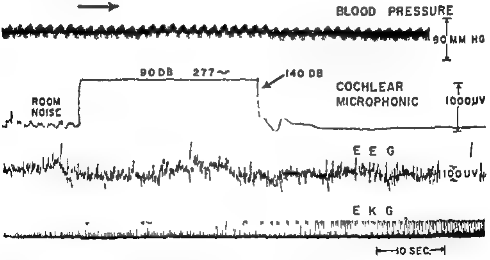

Fig. 5. Strip of continuous record (moving in the direction of the top arrow) of blood pressure, cochlear microphonic, electroencephalogram and electrocardiogram illustrates the kind of information obtained for studying the relation between cochlear blood flow and cochlear function. The sustained 1200 microvolt response from the third turn to 277 cycles at 90 DB was suddenly obliterated by a 140 DB stimulus beginning at arrow in microphonic channel. Moving pictures taken before, during and after this acoustic trauma recorded simultaneously cochlear blood flow in the fourth turn.

TABLE 3 *Representative changes in blood flow, microphonic and organ of Corti, during acoustic trauma*

Note the tendency towards increased flow rates with increased end organ damage along with progressive reduction of microphonic as stimulus intensity increases

Frequency cycles	Intensity db	Exposure time, min	Blood flow maximum % change during acoustic trauma	Microphonic maximum % drop during acoustic trauma	Changes in organ of Corti
277	120	10	3, 15	42	0
		10	8	58	0
		10	10	—	—
		20	17	—	0
277	130	10	26	65	0
		10	30	87	0
		10	31	79	0
		30	15	—	0
277	135	10	25	—	–
		15	58	—	+ –
		20	103	—	+ + +
		20	47	—	+ + +
277	140	5	18	90	+ + +
		10[a]	84	91	+ + +
		10	87	70	+ +
277	150	10	23	100	+ + + +
		10	41	—	+ + + +
		10	116	—	+ + + +
		10	127	—	+ + +

[a] Actual values plotted in Fig. 4

A stable physiological and cardiopulmonary condition of the animal can be maintained for many hours as revealed by such parameters monitored as the E E G , E K G , pulse pressure and respiration Velocity of blood flow under *normal conditions in various segments of this terminal vascular bed* varies with the type of vessel and its diameter but continues at a constant rate in any one vessel segment Some normal values are listed in Table 1 As is seen in the table, blood flow velocity is least in the capillaries of the stria vascularis and is considerably higher in the radiating arteriole

Moderate acoustic stimulation (i e 90 db at 277 cycles) produces no visible change in blood flow rate or in diameter of the exposed vessels The microphonic response from the third turn is generally about 1 millivolt to this stimulus Some representative values are listed in Table 2 along with cochlear blood flow rate, pulse pressure and heart rate With greater acoustic stimulation lasting from 1 30 minutes blood flow rate may increase promptly, while dilation in the observed vessels is only occasionally seen and all the

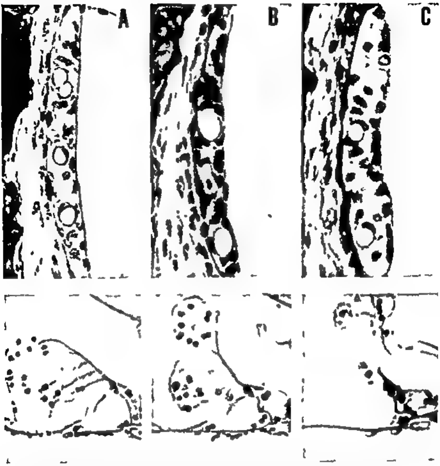

Fig. 6. Photomicrographs of stria and organ of Corti from apical turns of three cochleas exposed to various degrees of acoustic trauma with a 277 cycle tone and immediately perfused. A: 130 DB for 10 minutes. B: 140 DB for 10 minutes. C: 150 DB for 10 minutes.

Note absence of damage to the stria vascularis in A and B and oedema in C. The oedema of the stria in C was associated with rupture of Reissner's membrane in the same region of the cochlear duct.

vessels continue to carry blood except during very strong stimulation (153 db at 277 cycles for 10 minutes) when flow in an occasional vessel appears to stop. When the sound is turned off, flow in these vessels may return abruptly. When stimulation ceases, blood flow rates usually return towards preexposed values within 30 minutes. The microphonic responses to these stimuli show severe prolonged depression (see Figs. 4 and 5) and this is corroborated by histological evidence of hair cell damage or destruction in the organ of Corti when sounds above 135 db are introduced for over 10 minutes.

Narrowing of blood vessels, rupture of vessels, cessation of blood flow or definite reduction in flow rate, except as noted above, has not been observed even with the most intense stimulation, i.e. 153 db for 30 minutes.

As is seen in Fig. 5, these intense stimuli did not affect the animal generally, the pulse pressure, E.E.G. or E.K.G. did not change.

In Table 3 are listed some correlations between changes in cochlear blood flow rate, cochlear microphonics and cellular changes in the organ of Corti in response to acoustic trauma. A trend of increased flow rate with increased acoustic stimulation appears in the figures. The sudden appearance of hair cell damage for stimuli above 135 db is also evident.

In all cochleas exposed to 150 db or more for 10 minutes, rupture of Reissner's membrane was regularly produced in the upper turns and in this region oedema of the stria vascularis was also noted. End organ damage for these exposures extended to the basal turn. In Fig. 6 histological changes in the organ of Corti and the adjacent stria vascularis of the 4th turn for three intensity levels are presented. Absence of vascular damage in the strial vessels is evident.

DISCUSSION

The response of the cochlear vessels to excessive cochlear stimulation corresponds to that observed for the cerebral vessels where increase in pial vessel diameter to twice normal is reported one to two minutes after induced seizures in the monkey (Meyer & Portnoy 1959). The vessels observed were 20 to 100 μ in diameter. Even with post seizure paralysis experimentally produced, they observed persistent flow throughout with a cyanotic appearance of the veins. Under normal conditions, as observed through cranial windows, the velocity of red cells passing through the pial vessels is remarkably stable (Forbes 1958). Metrazol induced seizures are associated with increased blood flow, at first with a rise in cortical oxygen tension measured with the polarograph and then with a drop in oxygen tension, even though thermistors indicated increased blood flow (Meyer & Portnoy 1959). With strychnine induced seizures they found that local oxygen tension dropped to near zero.

Photic driving of the strychninized occipital lobes of the monkey increases electrical activity and causes a localized immediate rise in P_{CO_2} and, within 15-30 seconds, an increase in blood flow measured with a thermocouple and an increase in P_{O_2} as measured with the polarograph (Meyer & Gotoh 1960). The latter two values are elevated for several minutes after the stimulus has stopped, while the P_{CO_2} value drops more abruptly.

An earlier report indicates that after a seizure the polarograph records a decrease in oxygen tension near a venule but not near the corresponding arteriole, indicating an increase in oxygen consumption by the adjacent cortex (Davies & Remond 1947). The oxygen tension in the cochlea during acoustic stimulation has been reported to be reduced (Misrahy *et al.* 1958, Koide *et al.* 1960). This was interpreted as reflecting reduction in blood flow in the cochlea or increased oxygen utilization of the cochlea. No effect on capillary permeability to hydrogen was found. Direct observation of blood flow in the cochlear vessels was not made. The above findings fit in well with those made on the cortex after seizures and appear to reflect increased oxygen utilization of cells in the cochlea upon increased functional demand. Our

observation of increased cochlear blood flow only during very strong acoustic stimulation indicates that despite increased delivery of oxygen as indicated by the increased blood flow a reduced oxygen tension in the cochlea reported by them is probably due to an increase in rate of oxygen utilization beyond the available rate of oxygen supply.

While dilatation of larger vessels on the surface of the cortex follow excessive stimulation (seizures) the vessels in the terminal vascular bed of the stria and spiral ligament do not show dilatation to excessive stimulation. Instead changes in blood flow rate through these vessels are observed and probably reflect dilatation of feeding vessels (arteries in the modiolus) outside the observed field perhaps responding to locally increased CO_2 production. For the stria vascularis it would seem that changes in flow rate is the primary response in this functionally important part of the vascular bed. Our observations indicate that a wide variety of flow rates are compatible with normal cochlear function as reflected in the cochlear microphonic response (see Table II). This may be explained by the fact that respiratory enzymes *in vitro* can maintain a steady state of activity as they use up oxygen at a constant rate until very low oxygen tensions develop (Chance 1957). They might do this *in vivo* by altering the amount of oxygen extracted from the supplying source (capillary) per unit time with alteration in blood flow rates. Increase in extraction rate of oxygen would be seen by a polarographic electrode as a decrease in oxygen available. Conversely increased blood flow rate or oxygen supply would be sensed by the platinum electrode as increased oxygen tension or oxygen available. The adjustments of flow rate and oxygen extraction rate in the coronary vessels of the heart with changes in the work of the heart are a close corollary (Katz 1960). For leg muscle the demand for increased oxygen in moderate exercise is apparently met mostly by increase in the extraction rate of oxygen with a minimal increase in blood flow. In heavy exercise increased oxygen demand is met mostly by increase in flow rate and to a smaller degree by increase in oxygen extraction (Reeves *et al.* 1961).

As with the brain the ability of the cochlea to function at a constant level even when blood flow rate changes may be related to the findings that equalization of gases in the pulmonary capillaries is completed after the blood moves only a fraction of the total length of the capillary. Flow rates through pulmonary capillaries are thus more than adequate for the blood to carry out the gas exchange. Equilibration may thus be possible in the pulmonary capillaries even with fast flow rates. Below some value not ascertained flow rate drop would also seriously affect oxygen delivery and thus cell function. The average time that blood cells flow through the pulmonary capillary is 0.75 seconds. Equilibration of this blood as it enters the capillary at an oxygen tension of 40 mm Hg with the oxygen tension in the alveolar air of 100 mm Hg is almost complete within 0.3 seconds (Comroe *et al.* 1955).

The special anatomical arrangement of the stria would afford a relatively

long vessel segment and long time i e 5 seconds for gas exchange In general time spent by blood cells flowing through capillaries is about 1 second at a flow rate of about 500 μ per second with an average capillary length of 500 μ (Bard 1956)

The cause of increased flow rate in the strial capillaries following very strong acoustic stimulation is probably the local increase in CO_2 with increased metabolism effecting a dilatation in the larger vessels This is known to be the most likely homeostatic mechanism adjusting blood flow to function Carbon dioxide is the most powerful vasodilator for cerebral vessels although anoxia and certain products of cell metabolism may also play an important part

CONCLUSIONS

Values for blood flow rates in the stria vascularis under stable cardiovascular conditions are reported along with the microphonic response

Direct examination of the vessels of the stria vascularis during strong (120 db) acoustic stimulation does not reveal either vasoconstriction or dilation while at the same time a marked reduction in microphonic response is recorded

An increase in blood flow rate in these vessels can be measured after very strong acoustic stimulation (135 to 153 db) when microphonic response is further impaired or permanently abolished

The way in which enzyme systems in cochlear cells might utilize oxygen under normal variations in blood flow and with moderate and strong acoustic stimulation is discussed

ZUSAMMENFASSUNG

Einige Normalwerte der cochlearen Durchblutunggeschwindigkeit der cochlearen Funktion (microfonische Antwort auf 277 cycles bei 90 db) des Carotispulsdruckes und der Herzfrequenz in Zusammenhang mit Veranderungen durch exzession akustischen Reizung

Die Relation von cochlearer Durchblutung zum Sauerstoffbedarf der Cochlea wird aufgezeigt

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Section of Otolaryngology University of Chicago, Illinois

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THE TREPHINE PUNCTURE METHOD IN DIAGNOSIS AND THERAPY OF DISEASES OF THE FRONTAL SINUSES

M. R. Antoniuk
Moscow, U.S.S.R.

From the Clinic of Diseases of the Ear, Throat and Nose (Head: Prof. B. S. Preobrazhensky) of the Therapeutical Faculty of the 2nd Moscow Medical Institute of N. I. Pirogov

The new instrument described was used to perform 93 trephine punctures on 85 patients with various diseases of the frontal sinuses for diagnostic and therapeutic purposes both in hospitals and in out-patient departments. After trephine puncture before and after local treatment all the patients received contrast roentgenological examinations of the frontal sinuses with lipiodol.

In 11 cases free sinuses were found, while the usual X-ray films showed them to be opaque.

Sixty-two patients were treated by flushing of the frontal sinuses and local introduction of antibiotics (penicillin, streptomycin, furacillin) and other drugs through a cannula. Such treatment gave good results.

Twelve patients, mainly with irreversible chronic diseases of the frontal sinuses, were operated on.

In spite of the great success of roentgenography in investigating the frontal sinuses, scientists very frequently encounter divergence in data obtained by routine roentgenography and by other methods of clinical examination.

It is therefore understandable that a number of specialists have attempted to develop a method of roentgenological examination of the nasal sinuses with radiopaque solutions to facilitate the elucidation or specification of the character of the lesion, its localization and extension.

The roentgenological examination of the nasal sinuses with radiopaque solutions was at first fortuitous. The most difficult part was the introduction of the radiopaque solution into the sinuses. Proetz (1926) and other authors introduced it by an "indirect method". Fraser (1927) introduced it through a cannula pushed through the fronto-nasal canal. In 1930 Sternberg & Satz used "Valsalva's test" to fill the frontal sinuses with radiopaque substance. In 1932 Reed's work on the filling of nasal sinuses by the "reverse Valsalva" method was published. In 1934 Pihrt wrote a work on the possibility of using Reed's method.

In the presence of inflammation in the nose and the sinuses introduction of the radiopaque solution into the frontal sinuses by the above-mentioned

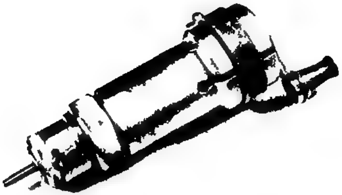

Fig 1 Apparatus for trephine puncture of frontal sinuses with mechanical device

methods is impossible Hence the failure of these methods to receive wide acceptance

A number of authors (Kummel Beck Zange and Moser Jorgensen & Melgaard Lemoyne Leroux Ruttenburg Meyer Potapov *et al*) in cases where the flushing of frontal sinuses endonasally was not successful owing to some cause or other resorted to puncture of the frontal sinuses by various methods for diagnostic and some also for therapeutic purposes Some used electric drills others in order to prevent the drill sliding over the bone made a notch on the bone with a trocart and hammer and removing the trocart drilled the bone And still others punctured the frontal sinuses by drilling the anterior wall of the frontal sinus with a drill attached to a dentist s drilling machine

Our observations show that the passing of the drill through healthy skin and soft tissue inflicts undesirable trauma on the soft tissues and later on the contact of the drill with the bone leads to the sliding of the drill over the bone which may hurt the adjacent tissues of the forehead and the orbit

Besides this the methods of the above mentioned authors proved to be insufficiently perfect as far as the safety of puncture is concerned Maybe this is why these methods did not receive a sufficiently wide acceptance in medical practice

Attaching great importance to the contrast roentgenological examination of maxillary sinuses we at Prof Preobrazhensky s suggestion have decided to try to improve the method of introduction of the radiopaque solution into the frontal sinuses for diagnostic purposes

We came to the conclusion that the external approach by puncture should be tried in a certain number of cases

As a result of investigations we together with an engineer, Mr E V Pavlov, designed a new instrument in 1957 It was described for the first time in our paper published in 1958 (Antoniuk 1958) This instrument (Fig 1) causes minimum damage to the skin and soft tissue of the anterior wall of the frontal sinus by cutting through them it ensures reliable fixation of the drill on the puncture site thus preventing the slipping of the drill over the bone

Our instrument for the trephine puncture of the frontal sinuses consists of a round knife with a drill in it also of a guard catch that limits the depth of the drilling depending on the thickness of the bone which is preliminarily calculated with the aid of X ray films taken in lateral projection The instrument may be attached to any drilling machine mechanical pneumatic or electric It may be ordered from the Tekhnolog factory in Moscow USSR

Anatomical Considerations

To find out the point of choice for the trephine puncture in the anterior wall of the frontal sinus we carried out special anatomical studies The study of innervation and vascularization of the soft tissue in the frontal area including the part corresponding to the anterior wall of the frontal sinus helped us to avoid damage of nerves and blood vessels during trephine puncture From available literature it can be seen that a number of authors (Kummel 1921 Beck 1937 Lemoyne 1947 Meyer 1955 and others) when puncturing the frontal sinuses did not take into account the interrelation between the interior wall of the frontal sinus and the vascular and nerve trunks that pass through this area These authors though they did propose this or that definite point for puncture of the frontal sinuses obviously did not pay sufficient attention to the fact that blood vessels and nerves may pass through the spot designated by them as the point of choice

We have studied the nerves and the blood vessels of the soft tissues of the forehead on six cadavers (2 men and 4 women) The nerves and the blood vessels of the afore mentioned area were isolated by the usual fine anatomical dissection During the dissection especial attention was paid to the methodical layer after layer separation of the skin subcutaneous tissue and fasciae

As a result of our anatomical examinations we have become convinced that the facts we have obtained on the innervation and vascularization of the frontal area do not on the whole contradict the main anatomical data in the literature and permit us to find out the topographic interrelations of interest to us

Our anatomical preparations show that the frontal area is innervated mainly by n supraorbitalis and ramus frontalis n frontalis The vascularization of this area is ensured by a supraorbitalis and a frontalis The veins with the numerous anastomoses found here exceed in calibre the accompanying arteries

Investigations showed that the nearest and furthest points of emergence

of ramus frontalis n frontalis in the frontal area on the right as well as on the left are almost equidistant from the midline of the forehead the distance being 15–20 mm

Thus the least vulnerable area (as far as the ramus frontalis n frontalis is concerned) is not further than 15 mm from the midline of the forehead along the intrasupraorbital horizontal line i e the line connecting the highest points of the supraorbital ridges

The supraorbital nerve in the frontal area runs much more laterally to the area that interests us and cannot be damaged as it is never nearer than 24 mm to the mid frontal line

The trunks of both nerves which interest us divide into primary and secondary branches at an angle to the initial trunk which varies between 20 and 90°

However most branches are at a minimum angle or run parallel to the main trunk thus an area is *formed between the trunks* of the nerves and their branches that is relatively free from the large nerve branches The main trunks of these nerves are also lateral to the midline at a slight angle

This is also one of the conditions ensuring the presence of areas relatively free from the more or less important nerve trunks

As to the n supraorbitalis it is much more lateral i e at a smaller angle with the intrasupraorbital line

The arteries and veins of the frontal area usually run along the corresponding nerves and at the emergence point at the supraorbital notch or the supraorbital foramen the nerves and the blood vessels lie closely to each other In the area of the supraorbital ridges these three elements of the neuro vascular bundle diverge slightly and occupy transversely some 5 6 mm of space higher up they spread out over a wider area

It must be noted that the frontal vein is nearer to the midline and its diameter varies between 1 5 and 3 mm and exceeds the calibre of the arteries and nerves The diameter of the v supraorbitalis is much smaller

As our observations show there are areas in the forehead that are free of more or less large nerves and vascular trunks or their branches

Firstly the area near the midline of the forehead reaches several centimetres in height and nearly 1 cm in width This area is wider along the intrasupraorbital line (approximately 20 mm) and is nearly 10 mm in the upper part In its middle part it reaches 14 15 mm

A second similar area is found symmetrically between the main neurovascular bundles of the forehead i e between the frontal artery and vein with the ramus frontalis n frontalis medially and the laterally placed second main neuro vascular bundle of the forehead consisting of the supraorbital artery vein and nerve This area is not only laterally placed but also higher and is slightly smaller in size than the middle area It has an ellipsoid shape and is widest in the middle (about 12 15 mm) it is located 10 12 mm from the mid frontal line The centre of this area is 15 17 mm from the supraorbital ridge

Fig. 2. Anatomical preparation of a male cadaver, aged 65 years. Innervation and vascularization of the forehead (personal study). 1, N. supraorbitalis; 2, r. frontalis n. frontalis; 3, anastomosis between 1 and 2; 4, a. supraorbitalis; 5, a. frontalis; 6, anastomosis between 5 and 8; 7, a. dorsalis nasi; 8, a. angularis; 9, a. palpebralis medialis; 10, v. frontalis; 11, v. angularis; 12, v. dorsalis nasi; 13, anastomosis between the right and left v. frontalis; 14, v. supraorbitalis; 15, v. palpebralis superior medialis; 16, v. temporalis superficialis; 17, m. obliquus oculi superior; 18, cannula in the left frontal sinus after trephine puncture in the least vulnerable area; 19, arrow indicates the point of intended trephine puncture of the right frontal sinus.

As a result of these data we came to the conclusion that the least vulnerable point for trephine puncture of the frontal sinuses is that which lies on the intersection of two lines, one of which runs horizontally from the mid-frontal line and is 10–15 mm removed from it, and the other which passes from the supraorbital ridge vertically up and also is 10–15 mm away from it (Fig. 2). The further the point is from the midline, the higher it should be from the supraorbital line. This, in its turn, depends on the size of the frontal sinus. Naturally, the possibility of other variants and anomalies is not excluded.

Before trephine puncture it is necessary to find out the dimensions of the frontal sinuses and their localization with the aid of the antero-posterior and lateral X-ray films.

Fig 3

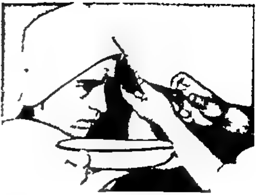

Fig 4

Fig 3 Position of patient at the moment of trephine puncture of the frontal sinus

Fig 4 Flushing of the right frontal sinus through a cannula after trephine puncture

THE TECHNIQUE OF TREPHINE PUNCTURE

Local anaesthesia (1% novocaine solution 0 5–1 ml with 1–2 drops of adrenalin (1 1000) of the front wall of the frontal sinus is given in a spot selected in advance 10–15 mm from the midline of the forehead and 10–15 mm from the supraorbital border taking into consideration the dimensions of the frontal sinuses and their localization from the X ray data The patient is supine when the puncture is made

Before trephine puncture the drill should be set for the depth required The following rules should be observed

1 To increase the length of the drill necessary for the penetration into the frontal sinus the screw guard is turned anticlockwise

2 To decrease the length of the drill the screw guard is turned clockwise In addition it is necessary to control the length of the drill by displacing the pin of the round knife (cutter) along the longitudinal slot The end of the drill which is inside the round knife is then exposed

The instrument with the round knife locked is placed strictly perpendicularly to the anterior wall of the frontal sinus The body of the instrument is held in the left hand As a result of the pressure on the instrument the round knife (cutter) having a conic form cuts the soft tissues and reaches the bones Then it penetrates slightly into the bone and fixes the drill in position preventing it from sliding over the bone After that the drilling is started (Fig 3) The drilling of the bone is done by turning the handle of the instrument clockwise with the right hand A few seconds later the drill immediately passes into the frontal sinus the operator feeling a fall into an empty space

After passing into the frontal sinus to remove the drill it is necessary to continue turning the handle the same way while pulling the instrument up so that the incised soft and drilled bone tissue will not fall into the sinus

Fig. ■ X-ray film, lateral view Left frontal sinus all filled with lipiodol Mucosa unchanged

After the drill is taken out, a cannula with a stilet is introduced into the 2 5 mm hole The exterior diameter of the cannula is equal to that of the drilled hole Then the stilet is taken out and a blunt needle, connected with Luer's syringe is introduced into the cannula

With the help of the syringe the contents of the frontal sinus are aspirated and then it is washed with warm saline (Fig 4) If injection of the solution into the frontal sinus shows that the fronto nasal canal is blocked, the flushing is done with a thinner needle (blunt) Then the washing liquid flows out through the opening between the cannula and needle

In purulent cases, it is nearly always possible to remove the pus from the sinus with a syringe

With this method the patency of the fronto nasal canal and the character of the contents of the sinuses can be noted, and the introduction of the opaque agent for diagnostic purposes for additional X-ray studies is facilitated

Depending on the presence of pathological changes thus found, the flushing of the frontal sinuses and the introduction of solutions of antibiotics (penicillin, streptomycin, furacillin and others taking into consideration the sensitivity of the microflora of the contents of the frontal sinuses to antibiotics) and the other drugs are carried out if necessary for therapeutic reasons

In 1957 1959 our hospital has thus examined 85 patients with various diseases of the frontal sinuses Among them there were 50 men and 35 women aged from 17 to 80 (5 cases from 17 to 20 years old, 29 from 21 to 30 years old 21 from 31 to 40 years old 17 from 41 to 50 years old ■ from 51 to 60 years old, 4 from 61 to 70 years old and 1 aged 79)

Fig. 6.

Fig. 7.

Fig. 6. X-ray film after filling of the right frontal sinus with lipiodol. Considerable uneven thickening of the mucosa of the frontal sinuses, communication between sinuses. The right fronto-nasal canal not patent. Lipiodol passes freely through the left fronto-nasal canal into the nasal cavity and simultaneously fills the maxillary sinus. Diagnosis: Exacerbation of bilateral chronic purulent frontal sinusitis.

Fig. 7. X-ray film, lateral view. Shadow of the cannula introduced into the right frontal sinus. Frontal sinus entirely filled with lipiodol. Contrast dye passes freely through the fronto-nasal canal into the nasal cavity and the ethmoid cells and simultaneously fills the main sinus.

These 85 patients were subjected to 93 trephine punctures for a diagnostic and also a therapeutical purpose. In 15 cases trephine puncture and further observations were carried out at the outpatient clinic and in the other 70 cases in hospital. No complications were seen after trephine puncture.

All patients had detailed clinical and X-ray examinations. Films were taken in 2 or 3 projections (frontal, mentonasal, frontal, fronto-nasal and lateral), so as to estimate the shape and dimensions of the frontal sinuses.

Contraindications to trephine puncture of the frontal sinuses were X-ray data of plain films—underdeveloped frontal sinuses (small in size) and also absence of definite borders of frontal sinuses (doubt of their presence).

After the trephine puncture of the frontal sinuses in all cases regardless of the character of the inflammatory disease X-ray examination with a radio-paque dye was carried out. Lipiodol was used as the contrast agent. The introduction of lipiodol into the frontal sinuses was done on patients in the X-ray room, the patients lying with their heads tilted slightly back. The amount of the lipiodol introduced depends on the dimensions of the frontal sinuses and on the pathological changes in it. Usually from 2 to 10 ml lipiodol

Fig 8

Fig 9

Fig 8 X ray film lateral view After introduction of lipiodol into the left frontal sinus Uniform thickening of the mucoperiosteal lining The left fronto-nasal canal patent Diagnosis Left chronic purulent frontal sinusitis

Fig 9 X ray film, anterior mento nasal projection Contrast dye introduced into the right frontal sinus through the inter sinus septum, with destructive changes passes into the left frontal sinus, fills it up and passes freely through the fronto nasal canal into the nasal cavity Uneven thickening of the mucoperiosteal lining of the right frontal sinus The right fronto nasal canal not patent Diagnosis Relapsing chronic purulent frontal sinusitis on the right side

are necessary to fill the frontal sinus After introduction of lipiodol no complications were noted

Contrast roentgenography was used by us to clarify the diagnosis, to find out the duration and exact localization of the pathological process, so as to work out the most rational plan of treatment Besides this, we used contrast roentgenography after completion of local conservative treatment so as to *follow the dynamics of the disease and find out the condition of the mucosa* of the frontal sinus

With unchanged sinus the contrast dye usually fills the entire cavity, forming, as it were a mould (Fig 5) If the fronto nasal canal is totally patent, then a part of the contrast dye oozes through the natural anastomosis of the sinus into the nasal cavity the ethmoid cells, and sometimes it penetrates into the maxillary and the main sinuses (Fig 6, 7)

In various forms of acute and chronic frontal sinusitis the contrast dye does not fill the sinus entirely owing to the thickening of the mucosal lining In such cases a strip like shadow is usually noted between the outline of the contrast dye and the bone wall of the sinus (Fig 8) The contours of the radiopaque dye shadow may be smooth or not This depends on the degree of

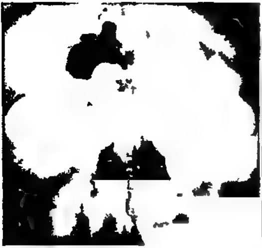

Fig. 10

Fig. 11

Fig. 10. A round filling defect in the right frontal sinus with even contour inside the radiopaque shadow. No patency of the fronto-nasal canal. Diagnosis: Cyst of the right frontal sinus.

Fig. 11. X-ray film shows small left sinus filled with lipiodol. Cannula shadow. Mucosa of the sinus unevenly thickened, fronto-nasal canal patent. Diagnosis: Left chronic purulent frontal sinusitis.

swelling or hypertrophy of the sinus mucosa. In cases of considerable swelling or hypertrophy of the mucosa the sinus cavity decreases markedly in size and is deformed. With considerable changes in the sinus and destructive changes in the intersinus septum the contrast dye penetrates from one sinus into the other (Fig. 9).

In cysts of the frontal sinus (if the contrast dye is injected into the sinus cavity outside the cyst) one can clearly see a round filling defect with a smooth contour in the shadow of the contrast dye (Fig. 10).

The practical significance of the contrast roentgenography may be correctly estimated only when the puncture of the frontal sinus, the examinations of its contents and the contrast roentgenological examinations following it are looked upon as a single diagnostic complex.

The classification of patients depending on the character of the inflammatory diseases of the frontal sinuses and the methods of treatment are shown in the table.

On the data obtained during trephine puncture of the frontal sinuses and additional contrast roentgenography we decided to perform surgical operations on [illegible] patients with chronic purulent frontal sinusitis, 1 patient with chronic polyp-purulent frontal sinusitis, 1 patient with chronic purulent relapsing frontal sinusitis, 3 patients with chronic purulent frontal sinusitis with fistulae and 4 patients with bilateral chronic purulent frontal sinusitis. All these patients received local conservative treatment after trephine puncture. But the pathological process in the frontal sinuses proved to be irrever-

TABLE 1 *The classification of patients by the character of the inflammatory processes of the frontal sinuses and the methods of treatment*

Diagnosis	No of patients	No of trephine punctures	Trephine puncture		Out patient department	Hospital	Contents of sinus			Patency of the frontonasal canal			Communication between sinuses	Treatment			Results of treatment		
			Right	Left			Pus	Serous	Absence	Free	Difficult	Absent		Conservative	Operation	Not necessary	Cure	Improvement	No changes
Acute catarrhal frontal sinusitis	2	2	2	—	1	1	—	1	1	1	—	1	—	2	—	—	2	—	—
Acute purulent frontal sinusitis	1	1	2	2	—	1	1	—	—	2	1	1	—	1	—	—	1	—	—
Sub acute catarrhal frontal sinusitis	2	2	2	—	1	1	—	—	2	1	—	1	—	2	—	—	2	—	—
Sub acute purulent frontal sinusitis	3	3	3	—	2	1	3	—	—	1	—	2	—	3	—	—	3	—	—
Chronic catarrhal frontal sinusitis	5	5	5	—	—	5	—	—	5	1	1	1	—	5	—	—	5	—	—
Chronic purulent frontal sinusitis	28	28	19	9	7	21	29	—	—	15	5	8	1	20	2	—	26	1	1
Chronic polyp purulent frontal sinusitis	1	1	2	2	1	3	1	—	—	2	1	1	1	1	1	—	—	2	2
Chronic purulent relapsing frontal sinusitis	6	7	3	1	—	6	7	—	—	2	1	1	1	5	1	—	3	2	1
Chronic purulent frontal sinusitis with fistulae	1	1	2	1	—	1	1	—	—	—	—	1	1	—	1	—	—	—	1
Exacerbated chronic purulent frontal sinusitis with symptoms of secondary serous meningitis	2	2	1	1	—	2	2	—	—	1	—	1	—	2	—	—	2	—	—
Bilateral chronic purulent frontal sinusitis	11	18	10	8	1	10	[illegible]	—	—	13	—	8	1	7	1	—	6	1	1
Cyst of the frontal sinuses	1	1	1	1	1	3	1	—	1	—	1	1	1	1	1	—	2	1	1
No pathological changes	11	11	8	3	1	10	—	—	11	11	—	—	—	—	—	11	—	—	—
Total	85	93	[illegible]	32	15	[illegible]	70	1	22	52	10	31	9	[illegible]	12	11	55	7	12

sible This irreversiblity was discovered by repeated contrast roentgenography after the completion of treatment

The pathological changes found in frontal sinuses during operations confirmed the data obtained by trephine puncture and contrast roentgenographical examinations

In 4 cases as a result of the trephine puncture and following contrast roentgenography cysts were detected One of these cases was subjected to a conservative operation on the frontal sinus taking into account the localization of the cyst During the operation the cyst was found and histological examination confirmed the diagnosis In 2 cases with cysts of the frontal sinuses we tried a special method of treatment using Gordeev s liquid No 2 (taking into account its necrotic effect on tissue) After 1 and 2 instillations respectively of 2 3 drops of Gordeev s liquid through the cannula the patency of the fronto nasal canal was reestablished and a yellowish fluid began to ooze from the frontal sinuses Then for 6 7 days these patients were given a daily flushing of the sinuses with warm saline and local injection of 200 000 I U of penicillin diluted in 2 ml of saline

As a result of the treatment given headaches disappeared Operations on the frontal sinuses became superfluous Four months and a year later respectively normal X ray pictures showed the frontal sinuses to be normal

In the 4th case of chronic purulent frontal sinusitis and cyst a considerable improvement was noted after local treatment (flushing of the sinus and introduction of adrenalin and penicillin) for 7 days in an out patient department The patient refused to have the cyst removed

In 11 cases we found free sinuses with contrast roentgenography of the frontal sinuses when ordinary X ray films showed them to be opaque According to the data obtained the patients needed no treatment

The other 62 patients received local conservative treatment depending on the character of the disease (see table)

In 55 cases clinical cure was noted (among them 2 cases of exacerbation of the chronic purulent frontal sinusitis with symptoms of secondary serous meningitis) and in 7 cases a considerable improvement was noted

Treatment consisted of daily flushings of the frontal sinuses with warm saline through a cannula and a following introduction of 3–4 drops of adrenalin (1 1000) penicillin (200 000 I U) and streptomycin (250 000 I U) diluted in 2 ml of saline or a furacillin solution (depending on the sensitivity of the bacterial flora of the contents of the frontal sinuses to antibiotics)

In acute sub acute and chronic cases if the fronto nasal canal was not patent patency was re established as a rule on the 2nd or 3rd day and patients noted considerable improvement

The cannula introduced into the frontal sinus was left there for 5 8 days on the average and in cases of chronic purulent inflammations for 10 20 days After treatment a control contrast roentgenological examination was made to check the dynamic of the disease

After the cannula was removed the wound usually healed in 5 6 days without leaving noticeable traces

ZUSAMMENFASSUNG

Das beschriebene neue Gerat wurde bei der Ausfuhrung von 93 Trepan Punkturen bei 85 Patienten mit verschiedenen Stirnhohlenerkrankungen fur diagnostische und therapeutische Zwecke sowohl in Krankenhausern als auch in Abteilungen fur Laufpatienten verwendet Die Stirnhohlen der Patienten wurden nach den sowohl vor als auch nach der lokalen Behandlung vorgenommenen Trepan Punkturen mit Lipiodol als Kontrastmittel gerontgt

In 11 Fallen wurden so freie Stirnhohlen festgestellt, die auf den gewohnlichen Rontgenaufnahmen undurchsichtig erschienen

62 Patienten wurden durch Spulung der Stirnhohlen und durch lokale Einfuhrung von Antibiotika (Penicillin, Streptomycin, Furacilin) und anderen Medikamenten durch eine Kanule behandelt Diese Behandlung brachte gute Erfolge

12 Patienten meist mit nicht beeinflussbaren chronischen Krankheiten der Stirnhöhlen, wurden operiert

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Kutuzovsky Prospect 9 17 apt 135 Moscow G 311

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PROTEOLYTIC ACTIVITY IN SUPRAVITALLY SHOCKED LUNG TISSUE

G. Herberts
Umeå, Sweden

From the Department of Otolaryngology (Head: Prof. G. Herberts), Royal Medical School, Umeå

Proteolytic activity in extracts of lung from 25 supravitally shocked guinea pigs showed a significant increase in comparison with activity in extracts from 22 normal animals not sensitised but otherwise similarly treated. The significance of using supravital shock in the study of inhibitory factors and their influence is discussed.

Cell damage accompanying anaphylactic reaction has been studied using various biological and chemical methods. Allergy phenomena in dermatological practice are often accompanied by lytic cell processes (Axhausen) which have been the subject of biological and histological studies. Biochemical methods have also been employed to study cell damage accompanying anaphylactic reaction and in recent years the disturbances in the enzyme chemistry of the cell have been observed. Above all, an increased proteolytic activity with anaphylactic reaction has been established. A similar increase in activity would seem to constitute an element in the cyclic course of the process of allergy and is to be regarded as a reversible process which is well governed both by intra- and extracellular inhibitory factors. It is possible that both the sensitising and shock releasing effect of antigen supply depends essentially on, in the first place, an influence exerted on these inhibitory factors. Secondary defence mechanisms released by the antigen–antibody reaction can also be considered to influence the biochemical reaction in the cell. In experimental studies of these reactions, therefore, it is highly desirable to exclude any inhibitory factors as far as is possible. If one works with tissue extracts or organ suspensions (slice method) taken from animals killed in the normal way, one must reckon to find the above mentioned inhibitory factors in the system. If, on the other hand, the extract is prepared from so-called supravitally shocked animals, one has the advantage of working with a purer system.

Supravital shock means that a sensitised animal is exsanguinated and perfused with a physiological common salt solution during artificial ventilation by tracheotomy. When the perfusion solution is blood free, a limited amount of antigen is transferred to it. In this way typical shock lung tissue is obtained.

In connection with continued studies of the influence of various inhibitory

mechanisms and their effect on proteolytic activity in lung extract a fairly large number of experiments involving supravital shock were carried out The results are reported on below

Method

Supravital shock was carried out as described above (cf Herberts 1955)

Preparation of extract

The lung was weighed and ground with fine quartz sand and distilled water was added (three times weight) Centrifuging for 2 min at 2000 rpm

Determination of proteolytic activity

After the antigen was added (0 1 %) digestion for half an hour at 56°C and for 90 mins at 37°C Samples were taken immediately before and after digestion Amino nitrogen determination according to the colorimetric method with ninhydrin after Moore & Stein (1954) In all cases double samples were taken

Material

Supravital shock was carried out on 25 guinea pigs which had been sensitised about 3 weeks earlier Exactly the same experimental process was used on 22 healthy (not previously sensitised) animals (350–450 g bucks)

Results

The quantity of amino N per gram of lung released after 2 hours digestion constituted the difference between values at 0 and 2 hours (see table)

Quantity of amino N per gram of lung released during 2 hours digestion

	Average (mg NH_2)
Normal animals (22)	0.108 ± 0.0105
Supravitally shocked animals (25)	0.140 0.0104

Difference 0.032 ± 0.015 (significant)

The results show that proteolytic activity in lung extract from animals after supravital shock is greater than the corresponding activity in extract from normal animals

DISCUSSION

With normal acute shock in guinea pigs there soon appear disturbances to capillary permeability the quantity of interstitial tissue fluid the blood supply the exchange of gases and other effects It is probable that these have a secondary influence on the cells biological and biochemical systems By

means of supravital shock a number of these effects can be excluded, wl the effect of supplied inhibitory factors can be studied Under these expe mental conditions the antigen to a large extent meets only with sensiti cells That in spite of this there is a clear increase in proteolytic activ argues strongly for the idea that increased proteolysis after antigen sup to sensitised cells is a primary and essential factor in the course of sho The results agree with earlier experiments using normal methods of releas shock.

ZUSAMMENFASSUNG

Die proteolytische Aktivität im Extrakt der Lunge von 25 supravitalgeschock Meerschweinchen zeigte eine merkbare Zunahme im Vergleich zu der Aktivität Extrakt von 22 auf gleichartiger Weise behandelten normalen Tieren Die Bedeut der Ausnutzung von supravitalem Schock an der Studie über die Einwirkung Hemmungsfaktoren wird in der Diskussion hervorgehoben

RÉSUMÉ

L'activisme protéolytique des extraits du poumon de 25 cochons d'Inde ap supravital choc a présenté un relèvement significant comparé avec l'activisme extraits de 22 animaux normals, analoguement traités L'importance d'utiliser choc supravital en étudiant l'effet des facteurs d'étanchement est présenté dans discussion

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Dept of Otolaryngology, Royal Medical School, Um

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THE CAUSE AND PRACTICAL IMPORTANCE OF OCULOGRAVIC ILLUSIONS

ULF BRANDT
Stockholm, Sweden

From the Medical Unit of the Royal Swedish Air Force and the Laboratory of Aviation and Naval Medicine, Karolinska Institutet, Stockholm

The oculogravic illusion can be interpreted as a specific otolith response to a stimulus consisting of linear acceleration. It has been suggested as a conclusive proof that the phenomenon does not occur in deaf subjects with labyrinthine areflexia. Two fresh cases of *acquired* labyrinthine areflexia have been examined in the human centrifuge, the illusion being measured by a special technique. Although abnormal illusion curves much unlike those recorded in the congenitally deaf may be obtained at the end of the "destruction stage", complete compensation with illusion curves resembling those of healthy individuals developed in a comparatively short time. The logical conclusion would be that oculogravic illusion cannot be accepted straight off as a selective measure for otolith sensitivity. In connexion with a discussion of analogies, comparing oculogravic and oculogyral illusion, the author suggests that the "lag effect" (i.e. the time necessary for reorientation on rapid changes of the angle of incidence of the resultant vector) may offer a more adequate expression for static sensibility. The recent advances in the methods of observing these labyrinthine illusions should add to our somewhat unverified knowledge of vestibular physiology and pathology.

When studying a sense organ—or a "functional" part of one—certain basic prerequisites have to be met. Thus the active stimulus should be specific to the organ in question, there should be an indicator for this stimulus and also it would be valuable to be able to make comparisons between individuals showing normal activity of the organ and others in whom it is partly or completely out of operation.

As far as the vestibular nerve is concerned, our usual clinical tests are actually based on these principles. The nystagmus test later to become generally accepted as a standard for the evaluation of vestibular function was introduced by Bárány (2). This sensitive ocular reflex has not gained its present clinical importance simply by accident: the symptom is easily observed and may be recorded by various recording techniques. It seems to be certain that there is nothing to express stimulation of the vestibular apparatus in a more adequate and objective manner. On the other hand there are still many unsolved problems concerning the neuro-anatomical connexions of the vestibulo-oculomotor reflex path in question, the central influence on this reflex, etc. The variations in the nystagmus response, great as they may be between

individuals and at different times in the same individual often cause considerable disappointment to the research worker Also the dubious significance of various nystagmus qualities and the relationship between the fast and slow component with respect to frequency and amplitude confuse interpretation Certain recent work (1 12) using nystagmography as a means have clearly *stressed the difficulties of interpreting this type of vestibular reaction*

Furthermore there is no evidence so far—though much work has been devoted to this topic—to prove that the static division i e the otolith organ of the inner ear could possibly cause any type of nystagmus

Other vestibular tests such as the pointing test arm tone reaction Romberg etc only lend themselves to qualitative evaluations yet they naturally retain their clinical value as important symptoms in differential diagnosis Without any intention of making this description complete I should also like to mention the determination (according to Bailliart (14)) of the tone of the retinal artery—one way of obtaining quantitative information about the influence of vestibular stimulation on the vegetative nervous system—and the Frenzel ner Preber apparatus (8) which utilizes the connexions between the central vestibular and autonomic nervous systems for the purpose of determining the sensitivity of the vestibular nerve

These tests and methods independent of nystagmus recording as they are should mainly be considered as expressing the sensitivity of the vestibular nerve as a whole and it would be a mistake to expect any particular selectivity from these procedures

Van Dishoeck Spoor & Roggeveen (5 6 7) and separately Graybiel have studied a phenomenon known as *oculogyral illusion* and so far little used in clinical physiology A person being rotated in the dark will experience not only the usual ocular reflexes and difference of tone but also a pre and post rotatory impression of turning and a seeming movement of a slightly luminous object which is in reality stationary in relation to himself When the angular acceleration is strong enough to cause stimulation of the labyrinth this oculogyral illusion is directed in the same direction as the rotation When a constant angular velocity has been reached a second reaction in the opposite direction will occur and then all apparent movement ceases After stopping a post rotatory illusion occurs reversed with respect to the initial direction followed by a second reaction in the opposite direction The oculogyral illusion should not be confused with the sensation of turning However there are close relations between the illusion and sensation cupulograms their curves running parallel These cupulograms are crossed by the nystagmus cupulogram The illusion is as well defined as the nystagmus and very easy to observe It seems to be a matter of a central process without any causal connexions with *nystagmus or the muscle tone of the eye Just like* the turning sensation the illusion is directly associated with stimulation of the semi circular canals where both labyrinths are destroyed there is no oculogyral illusion Van Dishoeck considers this symptom as useful as any other in[illegible] sign of stimulation of the semicircular canals and in any case

it is as good as the nystagmus response. In both cases there is a 20 per cent dispersion of the duration values. Van Dishoeck is of the opinion that findings such as, e.g., discord of direction and duration of both phenomena may offer useful clues in judging dubious oto-neurological conditions.

The analogue of oculogyral illusion when the stimulus consists of a linear acceleration, i.e., oculogravic illusion, has been interpreted for certain reasons and by certain workers as the missing sensitivity indicator for the otolith organ which is so difficult to define accurately. After studying this phenomenon in the human centrifuge one may come to rash conclusions, maybe under the influence of the original experiment by Kreidl (13) using crayfish with metal particles substituted for the grains of sand in their rudimentary balance organ and making them vary their swimming position in accordance with the changes of a magnetic field. It would hence seem reasonable to believe that the variations in a *dynamic* field of force would produce the same specific result as a *magnetic* field.

The following characteristic features and properties seem to be in favour of the above mentioned analogy. The stimulus is an inertial force, the direction of which is the vectorial sum of the acceleration due to gravity and the active centrifugal force, hence its physical character is quite comparable to that of gravitation. A subject sitting in a strictly vertical position and exposed to a resultant force whose direction deviates from gravitation has a sensation of being tilted. There is an obvious analogy to the turning sensation following from rotation. When observing in the dark a luminous object which is stationary in relation to his own position, the person under test sees this object slowly moving until finally it occupies a definite spot in the room. It is easy to discover certain analogies between this process and oculogyral illusion.

The prerequisites of oculogravic illusion are rather easy to arrange in human centrifuges. Exact measuring and determination of the oculogravic illusion is carried out by means of the apparatus and recording technique previously mentioned (2).

According to a very old observation, which has been further investigated by Graybiel, the illusion does not occur in some alabyrinthine, congenitally deaf individuals. For this reason the illusion has been considered a specific expression of otolith sensitivity. In a previous paper I pointed out that as an important piece of evidence in favour of this theory it would be wise to select test subjects who had lost all labyrinth activities as *adults*, i.e., they would have been in possession of "normal" experiences with regard to space and position. In a number of experiments of a later date Graybiel *et al.* (11) took another step in this direction by comparing illusions in normal individuals with those of patients subjected to unilateral labyrinthectomy in the course of treatment of Ménière's disease. No particular differences being found, Graybiel came to the conclusion that in this respect *one* vestibular apparatus could meet all demands otherwise made on *two* labyrinths.

This gave a special impetus to following up new cases where both laby-

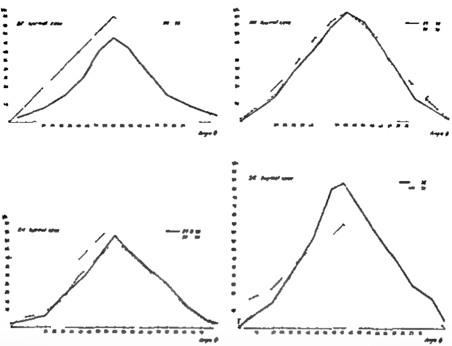
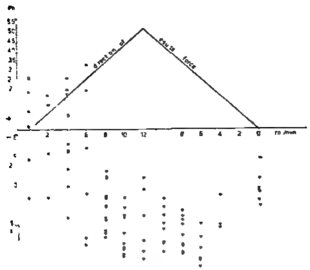


FIG 1 Illusion curves obtained from healthy individuals Each point on the curves represents the mean of at least 10 markings In case HH the illusion (i e the angle between illuded and objective horizon) coincides with Φ (i e the angle between resultant vector and objective vertical) Markings done by cases BI and BH are below Φ throughout Case SR shows a clear tendency to overestimate his illusion considerably The curves mentioned are all well within or close to the normal range

rinths had become inactive and to studying their further development *Bilateral* destruction of the labyrinths being extremely rare it proved necessary to utilize cases of accidental inflammatory conditions that met the experimental requirements

In the course of a few months two patients were found who seemed to comply with the requirements in an ideal way They were about 40 and 45 years old and showed case histories of acute disease with severe vertiginous symptoms nausea and other indications of vestibular attack A few weeks after the onset of disease the two cases were investigated along the ordinary clinical lines the most important finding being a complete absence of excitability of the labyrinths using iced and warm water Though the symptoms gradually became less pronounced the areflexia of the labyrinths remained unchanged At the time the initial experiments in the centrifuge were started there were still some signs of labyrinthine disturbances It was impossible however to provoke nystagmus (spontaneous by varying the position of the head by rotation) In both cases there was some unsteadiness of gait but apart from this no oto neurological or neurological symptoms could be revealed Lumbar puncture and electroencephalogram negative In one case the hearing ability was almost unimpaired whereas in the other there was a bilateral reduction of perception most closely resembling the noise type



F o ▮ Illusion curve obtained from Case 1, showing a relatively fresh acquired bilateral labyrinthine areflexia This test was repeated several times Up to 6 r p m the illusion markings show a rather chance dispersion above, but also *below*, the Ⅱ line Owing to the type of dispersion no statistical mean can be determined

The two cases were designated "vestibular neuritis" by the examiners, yet without any conclusive statement as to the aetiology The case histories revealed nothing that could be associated with the present disease, a slight glaucoma was found in the older patient, however There was nothing to indicate that his giddiness might be caused by labyrinthine dropsy The bilateral labyrinthine areflexia was the only symptom that could be found on renewed examination and was probably due to a break in the vestibulo oculomotor reflex pathway or, most probably, of some central section The examination gave no clues to the location of this injury

After deciding that the centrifuge tests could be carried out without any serious inconveniences to the patients, the oculogravic illusion was measured according to the technique previously described

RESULTS

Fig 1 shows a number of illusion curves obtained from healthy subjects acting as controls Fig 2 shows the result obtained from the first of the two alabyrinthine cases As can be seen from this curve the markings varied considerably, in fact it was not possible to evaluate the figures statistically Even before starting the centrifuge the patient had great trouble in finding his horizon Then, when gradually increasing the rotational speed, i e, increasing the angle between the resultant vector and the direction of gravitation (which means a gradually more oblique angle of incidence against the patient), the subject was found to show more and more uncertainty and to concentrate his markings *below* the Ⅱ line Hence, the result was clearly

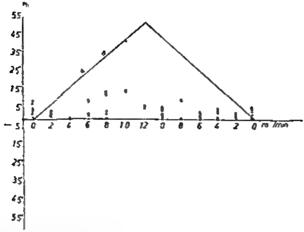


Fig. 8. Illusion curve obtained from a congenitally deaf subject with bilateral total labyrinthine areflexia. The markings are grouped mainly along the 0 line (i.e. lack of illusion) but always above it. Scattered peaks suggest a tendency towards illusion however.

paradoxical: not only did the patient lack the expected sensation of being tilted *outwards*, but he also at times experienced a sensation of being tilted *inwards* towards the axis of rotation of the centrifuge. Throughout the tests telephone connexions were maintained with the patient who could thus state his impressions which coincided with the markings. Thus, rather a lot of discomfort was experienced and the patient perspired; he also found a certain resemblance between his present sensations and the giddiness he had been suffering from previously. The tests were repeated several times at a few days interval, all results being similar.

It seems suitable here to introduce an illusion curve obtained from another alabyrinthine subject, a man with congenital deafness and total vesti-

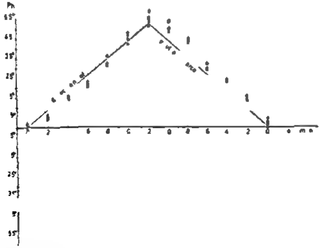


Fig. 9. Illusion curve obtained from Case 1 (above) showing an acquired bilateral labyrinthine areflexia (3 months later). Compensation is complete. There is nothing to distinguish this curve from the results obtained when studying healthy individuals.

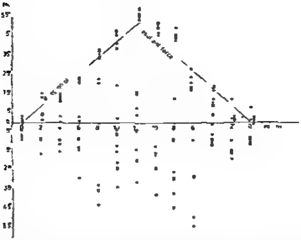


Fig 5 Illusion curve obtained from Case 2 showing an acquired, bilateral, labyrinthine areflexia The signs, 0000 indicate the initial result obtained at the end of the destruction stage As in Case 1 markings are dispersed freely both above and below the 0-line The signs, + + — indicate the markings about 2 months later, proving complete compensation

bular areflexia (Fig 3) There is a marked difference between this case and the patient with an acquired areflexia The markings are either concentrated to the 0 line, i e , indicating a lacking oculogravic illusion, or there are 'peaks in concordance with normal sensations (i e , a tendency towards illusion) No markings below the 0 line

These tests were repeated in the same patient three months later The subject had at this time recovered completely and had gone back to his work As already mentioned, his otological status remained unchanged and his vestibular apparatus showed no signs of reactivity From his illusion curve (Fig 4) it is easy to see that compensation is complete, his markings being arranged with the adequate precision along the slope of the resultant vector At present, there is nothing to distinguish him in this respect from a healthy subject

The other patient shows an almost identical picture (Fig 5) apart from the fact that the interval between the first (oooooo) and the second (+ — — — +) test was only about two months Even from this information it is clear that complete compensation has developed in only two months The comments are the same in this case

DISCUSSION

These experiments in a striking way confirm what was known already before that cases of vestibular neuritis leading to an extinction of the labyrinthine reactions are compensated rather quickly by the action of the other position indicating receptors (proprioceptors, exteroceptors, etc) without necessarily involving vision These patients very soon manage to solve their positional problems There was probably some weak vestibular activity

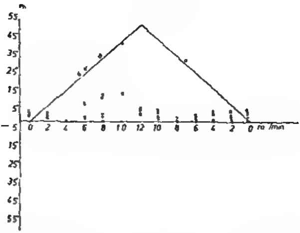


Fig. 3. Illusion curve obtained from a congenitally deaf subject with bilateral total labyrinthine areflexia. The markings are grouped mainly along the 0 line (i.e. lack of illusion) but always above it. Scattered "peaks" suggest a tendency towards illusion, however.

paradoxical: not only did the patient lack the expected sensation of being tilted *outwards*, but he also at times experienced a sensation of being tilted *inwards* towards the axis of rotation of the centrifuge. Throughout the tests telephone connexions were maintained with the patient, who could thus state his impressions, which coincided with the markings. Thus, rather a lot of discomfort was experienced and the patient perspired; he also found a certain resemblance between his present sensations and the giddiness he had been suffering from previously. The tests were repeated several times at a few days interval, all results being similar.

It seems suitable here to introduce an "illusion curve" obtained from another "alabyrinthine" subject, a man with congenital deafness and total vesti-

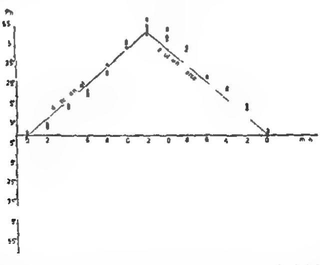


Fig. 4. Illusion curve obtained from Case 1 (above), showing an acquired bilateral labyrinthine areflexia (3 months later). Compensation is complete. There is nothing to distinguish this curve from the results obtained when studying healthy individuals.

able interest on the part of the clinicians However the two illusions have in common that they are very clear and rather well defined Also the physical prerequisites are comparatively simple As for the oculogravic illusion the tests here described should indicate a road to new methods of examination and hence add to our present knowledge of vestibular pathology poor though it may be in certain respects

RÉSUMÉ

L illusion optogravique a eté interpretée par certains auteurs comme une réponse spécifique des otolithes au stimulus d une acceleration linéaire La preuve de cette spécificite serait l absence du phénomene chez certains sourds muets presentant une totale aréflexie des labyrinthes Deux sujets presentant les signes d areflexie labyrinthique, *récemment acquise* ont ete examines dans la centrifugeuse humaine avec mensuration de l illusion par une technique appropriée Bien que, durant la phase finale de destruction[1] les courbes d illusion de ces sujets aient une physionomie nettement anormale ne ressemblant cependant pas à celles des sourds congenitaux elles s identifient après quelques mois sensiblement avec les courbes correspondantes obtenues avec des sujets sains indiquant une tendance très nette à la compensation La conclusion logique de ces resultats serait donc de ne pas accepter sans discussion l illusion optogravique comme mesure selective de la sensibilite otolithique En discutant par analogie, la nature des illusions optogyrique et optogravique il est suggere que le lag effect (c est a dire le laps de temps nécessaire à la reorientation consecutive à un changement rapide de l angle d incidence de la résultante vectorielle) pourrait bien être une expression plus adéquate de la sensibilité statique Les récents progres des méthodes d observation concernant les *illusions labyrinthiques* semblent indiquer une voie à suivre pour l elucidation des domaines encore mal connus de l équilibration

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ÜBER EINE HÖRHILFE ZUM BEIDSEITIGEN HÖREN FÜR EINSEITIG ERTAUBTE UND IHRE VORAUSSETZUNGEN

H. L. Wullstein und M. E. Wigand
Würzburg, Deutschland

Aus der Universitätsklinik für Hals-Nasen-Ohrenkranke (Direktor: Prof. Dr. H. L. Wullstein), Würzburg

Einseitig Ertaubte leiden oftmals sehr unter dem Fortfall ihres Binauralgehörs, da ihre Richtungsempfindung und das Wortverständnis nach der ertaubten Seite hin stark beeinträchtigt sind. Es ist möglich, durch Anwendung einer Hörhilfe diese Leistungen zu verbessern. Das Mikrophon wird am ertaubten Ohr angebracht, der Telefonausgang wird dem hörenden Ohr zusätzlich zugeleitet. Es werden einige Ergebnisse von Sprachverständlichkeitsmessungen im echofreien Schallfeld mit und ohne Störung wiedergegeben. Dabei wurde die durch die Hörhilfe erzielte Verbesserung der Diskrimination von einseitig Ertaubten geprüft. Außerdem konnte qualitativ gezeigt werden, daß bei Anwendung der Hörhilfe eine Verbesserung der akustischen Lokalisierung im Raum zu erzielen ist.

EINLEITUNG

Untersucht man Hörschwellen, wird man den Einohrigen kaum einer Normalperson unterlegen finden. Die vielbesprochenen 3 Dezibel, um welche die beidohrige gegenüber der einohrigen Schwelle gesenkt ist (z. B. Shaw, Newman & Hirsh, Chocholle), sind weniger, als unsere Audiometer-Stufenregelung u. a. zu messen erlaubt. Auch wurde ihre Signifikanz bestritten (Zwicker & Heinz), oder sie wurden als Wahrscheinlichkeits-Erhöhung der biologisch streuenden Schwelle errechnet (Licklider).

Aber der Ohrenarzt weiß, daß die akustische Ortungsfähigkeit des Einohrigen um Größenordnungen vermindert ist, sobald dieser in Tageslärm gerät. Richtungsgehör und gerichtetes Sprachverständnis sind aufgehoben oder entschieden herabgesetzt, weil das akustische Ziel nicht mehr vom Gehirn mittels binauraler Zeit- und Intensitätsdifferenzen angepeilt werden kann. Die akustische Zurechtfindung im Raum gelingt dem Einohrigen, wenn überhaupt, nur über Hilfsinformationen aus der Kopfwendung oder aus der Filterwirkung des Kopfschattens (Angell & Fite, Fletcher, Mathes, Mouzon). *Vielfach wird deshalb von einseitig Ertaubten Klage geführt über Behinderungen im Geschäftsleben u. a.* Es gelingt ihnen nicht mehr die Einstellung auf eines von zwei gleichzeitigen Gesprächen, die Anrede aus mancher Richtung wird überhört, und u. a. ist auch ihre Verkehrssicherheit im Straßenlärm stärker verringert.

Fig. 1. Schema der Hörhilfe für einseitig Ertaubte. Anbringung des Mikrophons *M* auf der ertaubten Seite, die durch Weglassung der Ohrmuschel gekennzeichnet wurde. Der Ausgang des Telefonteils *T* wird dem hörenden Ohr zusätzlich zugeleitet. Prüfung des Sprachverständnisses nach der ertaubten Seite im Störlärm

Diese Arbeit beschäftigt sich nun mit dem Gedanken, dem einseitig Tauben ein künstliches zweites Ohr zur Hilfe auf seiner ertaubten Kopfseite anzubringen und die darin aufgefangenen Schallsignale elektro-akustisch auf das hörende Ohr zusätzlich hinüberzuleiten. Fig. 1 soll eine solche Anordnung skizzieren. Die ertaubte Seite ist darin durch das Fehlen der Ohrmuschel gekennzeichnet.

Betrachtet man eine Hörbahnseite als einen Kanal für Sinnesmeldungen, so wird hier die Frage gestellt nach der sinnvollen Übertragung zweier paralleler Schallaufnehmer durch einen Kanal zum Gehirn. Gelänge diese Übertragung ohne gegenseitige Störung der beiden Eingänge, so wäre evtl. ein Informationsgewinn für den Einohrigen erreicht. In der Fernsprechtechnik wird die Übertragungsgüte von Leitungen durch Prozentmessung der Wortverständlichkeit getestet. Wir haben deshalb unserem Übertragungssystem (Fig. 1) vor allem Aufgaben mit Prüfung der Wortverständlichkeit gestellt.

METHODIK

Zur Untersuchung wurde der einseitig Ertaubte im echofreien Schallfeld mitten zwischen zwei sich zugekehrte Lautsprecher im Abstand von 130 cm gesetzt, die in Höhe seines Kopfes aufgehängt waren (FI HO P 260). Einer von ihnen war dem tauben Ohr zugewandt, der andere dem hörenden Ohr. Direkt oberhalb der Ohrmuschel des tauben Ohres wurde der Mikrophonteil eines Hörgerätes (Oticon, Mikrotechnik Stuttgart) fixiert. Über den leitungsführenden Kopfbügel war er verbunden mit dem Telefonteil des Gerätes, der hinter die gegenseitige Ohrmuschel zu sitzen kam. Von hier wurde ein kleiner Plastikschlauch locker in den äußeren Gehörgang geführt, der den Telefonschall zuleitete, ohne den Gehörgang abzuschließen. Auch nach Einführen des Schlauches hörte das betr. Ohr völlig ungestört den frei einfallenden Luftschall. Bei allen Proben wurde das Hörgerät auf eine geringe Verstärkung (10–15 db) eingestellt.

In den hier behandelten Versuchsreihen wurde ein Störgeräusch auf den dem normalhörenden Ohr zugewandten Lautsprecher geschaltet. Es bestand aus einer ununterbrochenen, raschen und relativ gleichmäßig lautstarken Sprache (vgl. Fig. 2). Diese gepegelte Sprache konnte bei genügender Laut-

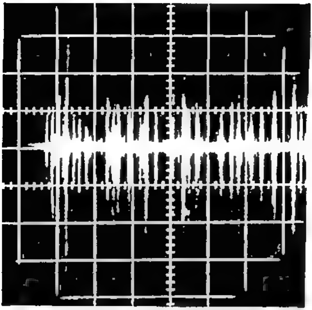

Fig. 2. Zeitverlauf der gepegelten Störsprache. Kurzer Ausschnitt. 1 cm = 1 sec. Oscillographische Registrierung vom Tonband. Erläuterung im Text.

stärke von allen Hörern gut verstanden werden. Es wurde jedoch verabredet, daß der Hörer diese Sprache nicht beachten sollte. Statt dessen sollte er auf Testworte lauschen, die aus dem Lautsprecher ertönten, der dem tauben Ohr zugekehrt war (vgl. Fig. 1). Störsprache und Testworte (Freiburger Einsilber u. *Hahlbrock*) wurden von zwei verschiedenen Tonbandgeräten abgespielt.

Die notwendigen Schalldruckmessungen erfolgten am Kopfmodell (Dummy) im echofreien Schallfeld mit Kondensatormikrophon und Mikrophonverstärker (Bruel & Kjær, Kopenhagen). Fig. 2 zeigt den oscillographisch registrierten Zeitverlauf der Störsprache zur Veranschaulichung der Dauerbelastung des Hörers mit einem verstehbaren und interessanten Sprachtext (Gerichtsteil einer Zeitung verlesen).

ERGEBNISSE

Es wurde eine Gruppe von zehn Patienten(innen) zwischen 30 und 65 Jahren untersucht, die aus irgendeinem Grund einseitig vollständig ertaubt waren, z. B. wegen Labyrinthausräumung bei Glomustumor, Fraktur, Grippe-Labyrinthitis oder Cawthorne-Operation. Um eindeutige Bedingungen zu haben, mußte das erhaltene Ohr in jedem Fall normalhörig sein. Alle Teilnehmer gaben an, daß die Gehörseindrücke nach dem Verlust eines Ohres qualitativ gleichgeblieben seien. Richtungshören und Sprachverständnis in geräuschvoller Umgebung gelangen jedoch nur schlecht.

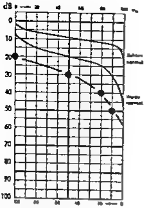

Fig. 3

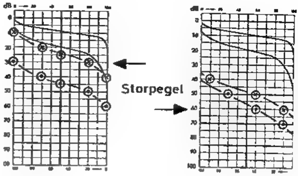

Fig. 4

Fig. 3. Sprachverständlichkeit des Einohrigen ohne Hörhilfe im echofreien Schallfeld. Testworte (Einsilber) aus Richtung des tauben Ohres. Ordinate: Schalldruck am tauben Ohr. Abszisse: Verständlichkeit in %. Vp. Jenn., F.

Fig. 4. Sprachverständlichkeit des Einohrigen im echofreien Schallfeld mit Hörhilfe nach Fig. 1. Testworte aus Richtung des tauben Ohres. Störsprache aus Richtung des normalhörenden Ohres. ← bezeichnet den Schallpegel der Störsprache. Ordinate: Schalldruck am tauben Ohr. Abszisse: Verständlichkeit in % beim Hören ohne Hörhilfe ○—○ und mit Hörhilfe ⊗—⊗. Vp. Jenn., F.

1) Qualitative Prüfung des Richtungsgehörs

Getrennt von dem unter „Methodik" geschilderten Vorgehen wurde zunächst eine Versuchsreihe durchgeprobt, bei der den Einohrigen jeweils 100 Klopfsignale aus 4 m Entfernung von 30° links, von 30° rechts oder von vorn angeboten wurden. Es wurden die richtigen und die falschen Antworten notiert, wie sie ohne bzw. mit angelegtem Hörgerät nach Fig. 1 erfolgten. Dabei zeigte sich, daß ohne Hörgerät keine signifikante Richtungserkennung stattfand, es sei denn nach gewissem Training.

Nach Anlegen des Hörgerätes kamen mehrere der Untersuchten sofort auf 70–80 % richtige Antworten.

2) Sprachverständnis ohne Hörhilfe vom tauben zum hörenden Ohr

Ertönten Testworte allein aus dem Lautsprecher, der dem hörenden Ohr zugewandt war, so entsprach die Verständlichkeit i. a. den Normallinien im Sprachaudiogramm für Kopfhörerprüfung (vgl. Fig. 3). Ertönten sie allein aus dem Lautsprecher, der dem tauben Ohr zugewandt war, so mußte für gleiche Verständlichkeit wie normal die Lautstärke durchschnittlich um 10 db erhöht werden (Fig. 3). Diese 10 Dezibel können als Dämpfungswirkung des Kopfes (Kopfschatten) für die benutzte Sprache angenommen werden.

3) Sprachverständnis ohne Hörhilfe im Störgeräusch

Ertönte gleichzeitig mit den Testworten aus Richtung des tauben Ohres eine Störsprache mit festgelegtem Lautstärkepegel aus Richtung des hörenden

Ohres, so wurde die Sprachverständlichkeit herabgesetzt. Fig. 4 gibt die Kurven wieder, die für einen Störpegel von 30 Dezibel bzw. 60 Dezibel galten. Für höhere Lautstärkepegel wirkte sich der Kopfschatten demnach weniger stark aus als für niedere Lautstärkepegel der Störsprache. Wurde mit 30 db gestört, so mußte, um 100%ige Diskrimination zu erreichen, die Testsprache den Störpegel um 30 db übersteigen. Bei Störung mit 60 db genügten 15 db Differenz.

4) Sprachverständnis mit Hörhilfe im Störgeräusch

Bei gleicher Signalanordnung wie unter 3), aber bei Verwendung der Hörhilfe nach Fig. 1, wurden die Verständlichkeitskurven verschoben. Fig. 4 gibt das Beispiel einer einseitig ertaubten Patientin wieder; für die übrigen Versuchspersonen gelten ganz ähnliche Werte. Die Kurvensteilheit wechselte allerdings von Fall zu Fall.

Sowohl bei niederen (30 db) wie bei mittleren (60 db) Lautstärken der Störsprache wurde mit Hörhilfe 80–90%ige Diskrimination der aus Richtung des tauben Ohres kommenden Testsprache erzielt, wenn diese nur so laut war wie die Störsprache. Die Verständlichkeit von 50% wurde sogar erreicht, wenn die Testworte leiser waren als die aufs hörende Ohr gehende Störsprache.

Von den 10 untersuchten Patienten interessierten sich nur zwei für den Erwerb einer solchen oder ähnlichen Hörhilfe für den täglichen Gebrauch. Die übrigen 8 zogen dem Tragen eines sichtbaren Gerätes am Kopf die Nachteile ihrer Gehörsbehinderung vor.

DISKUSSION

Im echofreien Schallfeld betrug der Kopfschatten für Sprache nach unseren Untersuchungen etwa 10 Dezibel. Der Kopfschatten beträgt bei der Prüfung mit Sinustönen nach Fletcher weniger als 5 db für die Frequenzen unterhalb 500 Hz und 10–30 db für die Frequenzen oberhalb von 3 kHz. Für die dazwischenliegenden Frequenzen, also für das Hauptsprachgebiet, beträgt er nach dem Diagramm von Fletcher gleichmäßig 7–8 db. Es liegt auf der Hand, einen Zusammenhang zu sehen zwischen den Messungen von Fletcher für einzelne Sinusoide und der Feststellung, daß auch für Sprache der Kopfschatten 10 db beträgt, also geringfügig größer ist als der Kopfschatten für die Hauptsprachfrequenzen.

Aus den unter 3) und 4) genannten Ergebnissen geht hervor, daß die Versorgung eines einseitig Tauben mit dem Überhör-Verstärker (vgl. Fig. 1) nach der tauben Kopfseite hin eine Verbesserung der Sprachverständlichkeit bewirkte. Einen gleichen Hinweis hat inzwischen E. P. Fowler Jr. gegeben. Diese Verbesserung wurde hier für verschiedene, im Berufsleben interessierende Störpegel untersucht, die speziell auf die hörende Kopfseite gerichtet wurden. Die Untersuchungen fanden statt im echofreien Raum, um

die Richtung des Schallflusses übersichtlicher anzuordnen. Dies ist natürlich im täglichen Leben, das sich fast immer in verhallten Räumen abspielt, anders.

Die Wirkungen des Überhör-Verstärkers wurde nicht für Hallbedingungen untersucht. Außerdem wurde nicht über die Grenzbedingungen berichtet, die z. B. bei Verwendung starker Intensitäten auftreten können, wenn der Verstärker übersteuert wird. Aus dieser Überlegung wurde der Verstärkungsfaktor des Gerätes auch kleingehalten. Statt an Verstärkung war lediglich an der Herrichtung eines Aufnehmers in der Gegend des ertaubten Ohres gelegen.

Ferner wurde der Einfluß der Phasenverschiebung im Hörgerät außer Acht gelassen, weil sie für diese Untersuchung keine Rolle spielte, da Störschall und Nutzschall im Zeitverlauf keinerlei Zusammenhang halten (Inkohärenz). Sie soll im Zusammenhang mit der Wirkung verzögerter kohärenter Signale auf ein Ohr getrennt untersucht werden.

Die hier geschilderten Versuche ahmten vielmehr den Vorgang einer willkürlichen Auswahl beim monauralen Hören gleichzeitiger verschiedener Schallvorgänge nach. Dabei interessieren andere begrenzende Umstände, z. B. wieviele Signale gleichzeitig einwirken dürfen, damit noch eine willkürliche, vernünftige Auswahl stattfinden kann. Es ist im Grunde die Frage nach der Informationskapazität der einen übriggebliebenen Hörbahn der Patienten. Ein solches Maximum an Auswahl ist für die Verwendung von gleichzeitig ertönenden Tonhöhen nach Daten Pollack's von G. A. Miller berechnet worden und beträgt etwa 2–2,5 bit, was die Unterscheidungsmöglichkeit zwischen 6 gleichzeitig gegebenen Tonhöhen bedeutet.

Ferner taucht die Frage auf, woran die Hörer eigentlich die Testworte erkennen, die doch zugleich mit einer verstehbaren Sprache von z. T. größerer Lautstärke auf dasselbe Trommelfell gegeben wurde. Vermutlich sind es Eigenheiten in der Grundtonhöhe, in der Klangfarbe und im Rhythmus der gesprochenen Worte. Wahrscheinlich sind auch diese Informationen aus der Frequenzsiebung durch das Hörgerät für die bessere Richtungserkennung im Raum mit dem Hörgerät maßgebend. Je nach dem Winkel zwischen hörendem Ohr, Schallquelle und Mikrophon entsteht ein anderes Zeitmuster der auf das Trommelfell treffenden Frequenzgemische.

So konnte „rechts" und „links" erkannt werden, je nachdem, ob das frei aufgefangene oder ob das im Hörgerät gefilterte Schallsignal in der Lautstärke überwiegt bzw. zeitlich früher eintrifft. Ein aufmerksamer Patient mit nur einem Ohr konnte daraus bald lernen, das Klangbild „rechts" vom Klangbild „links" zu unterscheiden.

Aus unserer kleinen Gruppe von Patienten haben sich nur zwei von zehn für den Erwerb einer solchen Hörhilfe interessiert. Z. T. möchte dies daran liegen, daß sie seit Jahren einseitig ertaubt waren und sich dieser Behinderung angepaßt hatten. Zum anderen waren sie fast alle Menschen ohne ausgeprägte berufliche und gesellschaftliche Anforderungen. Menschen dagegen, die durch ihre Stellung genötigt sind, auf der tauben Seite sitzende Gesprächs-

Definition of Terms

The following terms will be employed repeatedly and are defined here "Test ear" or "homolateral ear" the ear for which impedance is recorded "Contralateral ear" the opposite ear

Blowing Towards the Contralateral Ear

When a current of air is directed towards the contralateral ear in persons with normal hearing, an increase in impedance exactly similar to that obtained by acoustic stimulation is observed in the test ear This increased impedance may persist for several seconds when the air current is maintained The change in impedance is dependent on the force of the air current When this is increased the impedance of the tympanic membrane gradually rises until a maximal value is reached With intermittent air currents of constant strength the increase of impedance is equal each time, even when stimuli are applied in rapid succession In all these characteristics, the changes in impedance are similar to those seen when acoustic stimulation is employed

In suitable cases, i e patients with tympanic membrane defects we have directly observed bilateral contractions of the stapedius muscle, following both acoustic and air current stimulation These contractions vary with the stimuli after a pattern similar to that described above, and these observations confirm our idea that impedance changes are a result of middle ear muscular activity

The greatest changes in impedance are seen when the air current is blown into the auditory canal, but it may also follow blowing towards the surroundings of the ear (Djupesland, 1961) probably because part of the air current is then deflected into the ear duct If this is closed, as with a petrolated cotton swab, the changes of impedance in the test ear are greatly reduced and may disappear completely Such a complete fade out of the reflex is particularly frequent when the outer opening of the meatus is compressed by a finger

Apart from its cutaneous stimulation the air current also causes sound of considerable intensity The objection then, may be raised that this acoustic aspect of the air current is the real cause of the bilateral stapedius contraction which we have visually observed Certain observations tend to contradict this at least in part In persons with one deaf ear, blowing towards this may produce impedance changes in the opposite normal ear The acoustic aspect of the air current cannot be responsible for the reflex in these cases

The very act of placing a cotton swab in the contralateral ear meatus suffices to produce changes of impedance in the homolateral ear Such changes continue throughout the period while the swab is being moved When it comes to rest the impedance value returns to normal, only to increase again upon retraction of the swab Similar variations in impedance are seen when the contralateral meatus is being rinsed with water, as in a caloric vestibular

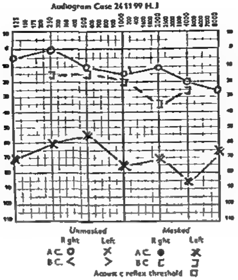

Fig 1

test Variations in the strength of the water current is the main factor causing changes of impedance With constant water flow, the impedance rapidly re turns to normal Variations in the temperature of the water appear to be of subordinate importance

As mentioned above, when the contralateral meatus is occluded, an air current towards this ear often fails to produce an increase in impedance Ob viously, the acoustic contribution is substantially reduced by this, but the tactile irritation of the auditory canal is also obviated

These observations lead to the conclusion that cutaneous nerve receptors in the auditory canal are the starting point of the intra aural muscular re flexes produced by blowing towards the ear However, another of our ob servations contradicts such a conclusion After anaesthetising the skin of the contralateral meatus and auricle, exactly the same changes in impedance as before are obtained, both by air current and acoustic stimulation Under these circumstances, the acoustic aspect of the air current may be presumed to be the reflexogenic agent In future work, we hope to clarify this enigma

When acoustic stimulation is used, the sound level of the contralateral ear must be 70–90 dB above the hearing threshold in order to cause a change of impedance in the test ear (Metz, 1946, Jepsen 1955) An exception is found in perceptive type loss of hearing with recruitment (Metz, 1952, Thomsen, 1955) However, in a number of cases it is not feasible to produce any reflex in the test ear, owing to the limited output available from commercial audio meters It is advantageous, then that with air current stimulation of the con tralateral ear changes in impedance may, as we have been able to demon strate be produced even when there is severe loss of hearing of either type in the contralateral ear

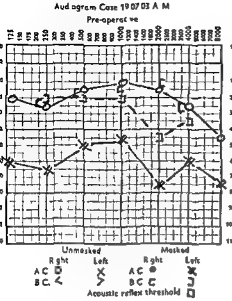

Fig 2a

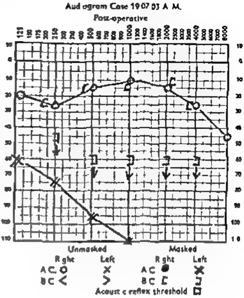

Fig 2b

Case 24/11/99 H J.

Male, aged 61, with long standing central perforation of the left tympanic membrane with periodic secretion Hearing (see audiogram, Fig 1)

Impedance recordings With the right ear as test ear, normal impedance increase is obtained by blowing towards the left ear, while none is seen with maximal acoustic stimulation After closure of the tympanic membrane defect (myringoplasty), without improved hearing, the same findings are again recorded

Case 19/7/03 A M

Female, aged 57 Purulent secretion from left ear for 12 years Otoscopic examination revealed a large defect in the left tympanic membrane with abundant granulations in the middle ear Hearing (see audiogram, Fig 2 a) Tympanoplasty was performed, followed by antibiotic therapy (streptomycin 5 g, penicillin 5 4 mega units) Postoperative audiometry (see audiogram, Fig 2 b) proved an almost complete loss of hearing in the operated ear, the cause of this is not clear

Impedance recordings With the right ear as test ear, blowing towards the left ear produced equal changes in impedance both pre- and post-operatively There was no change in impedance by acoustic stimulation of the left ear, either pre or post operatively

Even blowing towards the deaf ear when there is normal hearing in the other (test) ear may produce a change of impedance, this change generally being smaller than when evoked from a normal contralateral ear In some such subjects blowing towards the deaf ear will not cause any change in impedance in the test ear In these cases, more extensive neurological pathology appears to have interrupted the reflex path

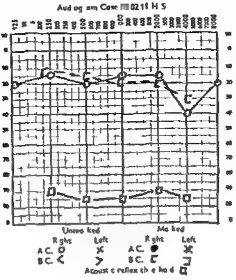

FIG. 3

Case 10/2/08 A. S.

Male, aged 3. After successful treatment (penicillin, sulphadiazine) of meningococcus meningitis at the age of 15 months, he appeared completely deaf, having previously shown normal development of hearing and speech. Examination showed normal otoscopic findings, bilateral abscence of caloric reactions.

Impedance recordings. No change of impedance in either ear with contralateral stimulation by air current or acoustically.

Case 13/2/11 H. S.

Male, aged 50. Following head injury with cerebral concussion at the age of 20, there had been no hearing in his left ear. Otoscopic findings were normal. Hearing (see audiogram, Fig. 3). There was no caloric reaction to ice water on the left side, normal caloric reaction on the right side.

Impedance recordings. With the right ear as test ear, no impedance change is seen with either air or acoustic stimulation of the left ear. With the left ear as test ear, normal impedance increase is obtained by blowing towards the right ear. The acoustic impedance threshold is indicated in the audiogram.

An obvious condition for the appearance of impedance changes is that the test ear must be mechanically able to react. No change in impedance is observed in cases where the test ear is affected by otosclerosis, middle ear exudate, poor tubal function, scarred and rigid tympanic membrane, or stapedius muscle paralysis.

Most workers (Metz, 1951, Jepsen, 1955, Klockhoff, 1961) have been unable to demonstrate contractions in the tensor tympani muscle on acoustic stimulation. In the main, our results agree with this. But in two of our patients operated upon for otosclerosis by the method of Schuknecht, in which, inter alia, the stapedius muscle is cut, small impedance changes in the operated

ear have been recorded Both air current and acoustic stimulation of the contralateral ear had this effect Such an effect was observed also when hearing in the contralateral ear was normal or but slightly reduced

Discussion

No definite conclusion can yet be drawn concerning the precise nature of the receptors concerned and the nerve pathways involved when an air current directed towards the contralateral ear produces impedance changes in the test ear The observed changes have characteristics similar to those which follow acoustic stimulation However an important practical difference does exist with air current stimulation the reflex may be provoked independent of the hearing in the stimulated ear provided that the reflex paths are intact and the test ear is mechanically able to react with a change in impedance

Direct Observation of the Tendons of the Intra aural Muscles

As briefly mentioned we have been able to observe the tendons of both intra aural muscles during surgical exposure of the middle ear Air current stimulation of the contralateral ear has consistently produced stapedius muscle contractions while no certain movements of the tensor tympani tendon have been observed with such stimulation Due to the considerable loss of hearing of conductive type in the contralateral ear acoustic stimuli have not been employed Our material is still too limited for any definite conclusions to be drawn

Upon voluntary contractions of the periorbital muscles or by blowing towards the orbital region (as described by Kloeckhoff) both intra aural muscles are seen to contract in most subjects With either type of stimulus the m tensor tympani stays contracted for a brief period only The first contraction of this muscle is a forceful one while succeeding contractions rapidly diminish in strength and finally cease entirely After a brief period of rest contractions of this muscle re appear

Blowing Towards the Test Ear (Homolateral Ear)

Impedance changes are also obtained when an air current is directed towards the test ear Certain precautions are important The air current must not be too strong The ear plug must be a close fit so that it will not change its

Fig 4 A Puffs towards homolateral ear *B* Blowing continuously towards homolateral ear *C* Blowing continuously towards contralateral ear

Fig. 5. *A*. Puffs towards contralateral ear. *B*. Puffs towards homolateral ear. *C*. Puffs towards cornea (ad modum Klockhoff). *D*. Voluntary contraction of the periorbital muscles.

position under the influence of the air current nor allow air passage past the plug. To avoid false recordings the auditory canal peripheral to the ear plug is stuffed with vaseline.

The impedance changes are smaller than those seen with contralateral ear stimulation. Another difference is that the change in impedance is not maintained on persistent stimulation but fades rapidly, finally to cease completely. After a rest period increased impedance is again observed. It should be noted that these characteristics are similar to those observed for contractions of the m. tensor tympani evoked by voluntary contraction of the periorbital muscles or by blowing towards the orbital region as described in the preceding section (Fig. 4 and Fig. 5).

A *summation effect* of stimuli has been observed by blowing simultaneously towards both ears and also by stimulating the contralateral ear acoustically when the test ear is exposed to an air current. This is demonstrated by the fact that subliminal stimulation of the contralateral ear together with subliminal stimulation of the homolateral ear may change the impedance of the middle ear (Fig. 6). If the stimulation of the contralateral ear is increased with either type of stimulus, blowing towards the homolateral ear may give further increases in impedance. This is not the case if the stimulus acting upon the contralateral ear is already sufficiently strong to produce maximal impedance increase in the test ear. Neither will blowing towards the orbital region give any further increase in impedance under such circumstances.

The detailed pattern of the impedance changes obtained by air current stimulation of the test ear depends also upon the interplay between the two intra aural muscles. With partial paralysis of the stapedius muscle, high brief and rapidly decreasing changes are recorded, probably due to a relative dominance of the m. tensor tympani. With recovery of the m. stapedius the impedance changes regain the pattern of normal subjects with lesser, more rounded amplitudes (Fig. 7).

Fig. 6. A. Subliminal blowing towards homolateral ear. B. Subliminal acoustic stimulation of contralateral ear + subliminal puffs towards homolateral ear. C. Supraliminal acoustic stimulation of (90 db, 100 ... and 110 db) contralateral ear + puffs towards homolateral ear.

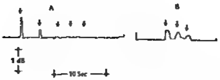

FIG 7 *A* Puffs towards ear with partial paralysis of the stapedius muscle due to rheumatic facial palsy (Bell s palsy) *B* Puffs towards a normal homolateral ear

We have made precisely the same observations by blowing towards the orbital region and by voluntary contractions of the periorbital muscles

As described by Klockhoff, when the intra aural chain of ossicles is interrupted, high brief impedance changes are observed when the m tensor tympani is brought to contract We have made similar observations when blowing towards the test ear in such cases Homolateral air current stimulation is well suited to diagnose such conditions The method will fail, however, in some cases, i e fracture of the temporal bone with reflex path interruption, or a ruptured tensor tendon

Following successful operations for otosclerosis by the method of Schuknecht, in many patients relatively high, brief, and rapidly decreasing changes in impedance are seen with homolateral air current stimulation The mechanism is presumed to be by way of increased motility of the conductive system They must be caused by contractions of the m tensor tympani, as the stapedius tendon has been cut

Klockhoff finds that a conductive type loss of hearing may be excluded with the aid of the electro cutaneous stapedius reflex, provided this can be recorded Our observations generally support his view, but with our method exceptions are found which should be considered in diagnosis This is illustrated by the following case

Case 6/5/48 A S

Female, aged 13 There was no history of ear disease, but on routine school medical examination at the age of 7, a conductive type loss of hearing was found in the right ear Hearing in the left ear, and otoscopic findings, were normal

Impedance recordings With the right ear as test ear, both air current and acoustic stimulation of the contralateral ear produce normal somewhat weak, increases in impedance Acoustic impedance threshold is indicated in the audiogram (Fig 8)

Blowing towards the test ear gives high rapidly decreasing changes in impedance, due to dominance of the m tensor tympani and to increased motility of the ossicular chain of the middle ear

With the left ear as test ear, acoustic contralateral stimulation gives no change in impedance due to poor hearing in the stimulated ear By air current stimulation, however normal increases in impedance are observed following stimulation both of the homolateral and contralateral ears

With surgical exposure of the right middle ear, the long leg of the incus was found to be replaced by a strand of fibrous tissue

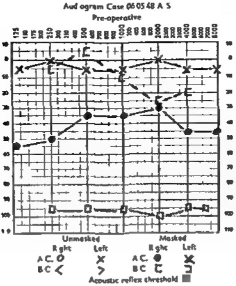

Fig 8

This case demonstrates that a recordable stapedius reflex does not definitely exclude a conductive type loss of hearing in the test ear

CONCLUSION

Air current stimulation of the external ear produces changes of impedance in the test ear, which can be recorded by acoustic measurement of the tympanic membrane impedance When the contralateral ear is thus stimulated, the observed changes in impedance are similar to those found with acoustic stimulation These changes are generally due to contractions of the stapedius muscle Air current stimulation is advantageous compared with acoustic stimulation in that it is independent of the hearing in the contralateral ear, provided the reflex path is intact The diagnostic scope of impedance measurements is thus substantially increased

When the test ear itself is exposed to an air current in many subjects impedance changes are observed which parallel those obtained by blowing towards the orbital regions, according to the method of Klockhoff These changes are probably the result of simultaneous contractions of both intra aural muscles The pattern of impedance changes is dependent upon the interplay of these muscles In cases of partial stapedius paralysis a definite tensor type reflex with high brief and rapidly decreasing impedance changes, is recorded This resembles the contractions of the tensor tympani muscle observed visually with the oto surgical microscope, and elicited either by voluntary contractions of the periorbital muscles or by blowing towards the orbital regions

RÉSUMÉ

Un aperçu est donné sur les réflexes musculaires intra-auraux provoqués par une stimulation d'air de l'oreille externe de l'homme. Une stimulation d'air est avantageuse comparée à une stimulation acoustique, puisque cette première est indépendante de l'ouïe de l'oreille contre latérale, pourvu que les voies de réflexes soient intactes. L'intérêt diagnostique de la mesure d'impédance est ainsi augmenté de beaucoup.

ZUSAMMENFASSUNG

Eine Übersicht ist gegeben von den intra-auralen Muskelreflexen hervorgeruft durch Blasen gegen das äussere Ohr des Menschen. Blasen ist vorteilhaft im Vergleich mit akustischer Reizung als dieser vom Gehör des kontralateralen Ohres unabhängig ist, angenommen die Reflexbahnen intakt seien. Der diagnostische Nutzen von Impedanzmessung ist damit bedeutend erweitert.

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Namsos Norway

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A RARE CYST OF THE PHARYNX

Harald Petersen
Sonderborg, Denmark

From the Ear, Nose and Throat Department (Head Jorgen Arnvig, M D), The State Hospital, Sonderborg

Large cysts of the pharynx and, particularly, of the oropharynx are extremely rare A large oropharyngeal cyst observed in a 30 year old man is reported The cyst was situated behind the right posterior palatine arch, adhering to the posterior wall of the pharynx The cyst was excised The genesis is discussed

As large cysts of the pharynx are very rare, publication of each new case must be of interest Rhinopharyngeal cysts are most frequent, while oropharyngeal and hypopharyngeal cysts are of greater rarity In a study of the literature, 31 pharyngeal cysts of variable genesis were traced they were reported in 23 papers including 10 of Italian origin However, in a number of these cases the original papers were not available, accordingly, the figures are partially based on reports cited by others

Twenty five cases were cysts of the rhinopharynx, including four bilateral (27, 28) In addition, four cysts of the oropharynx (6, 8, 9, 10) and two of the hypopharynx (5 23) were reported, the latter were situated in the pyriform sinus Cysts of the epiglottis or the base of the tongue are not included

Most of these cysts were considered to be of branchiogenic origin, while a few were regarded as retention cysts Mills (1955) described a cyst of the rhinopharyngeal vault and Lazzaroni (1956) reported two similar cases, all three were believed to have arisen from the Rathke pouch On the other hand, Keohane (1958) expressed the view that it would be more reasonable to conceive such cysts as having arisen from the rudimental bursa pharyngea In the neonatal period nasopharyngeal teratomata have been observed (12), whereas dermoid cysts proper do not seem to occur in the pharynx at all (11, 21) Kully (1935) pointed out that small retention cysts of the rhinopharyngeal vault are not rare, but are often overlooked

The rarity of large pharyngeal cysts as compared with lateral cysts of the neck is presumably due to the formation of the cervical sinus or vesicle in embryonic life From remnants of these formations a lateral cyst of the neck may easily arise A similar constriction of an epithelium lined cavity does not occur in the internal pharyngeal pouches While the branchiogenic origin in the frequent lateral cervical cysts is generally accepted, the genesis of simple pharyngeal cysts is less clear

When the cyst involves the lateral parts of the pharynx it is reasonable to

Fig 1

assume that it has arisen from an internal pharyngeal pouch The cyst is of unquestionable branchiogenic origin when it is associated with a lateral fistula of the neck Such a case was reported by Gill in 1950 His case and one of an isolated cyst of the oropharynx reported by Giussani (1928) are the only pharyngeal cysts in which the localisation and extent resemble the case described below

Case report

The patient was a previously healthy man, aged 30 On reporting to his physician after an acute tonsillitis, a swelling in the right side of the pharynx was disclosed The patient had not noticed anything abnormal, but his wife stated that he had shown a marked tendency to snoring during the last two or three years

On admission two days later, the tonsils were healthy they were small and deep seated Behind the right posterior palatine arch, and free of it was an ovoid smooth tumour, half the size of a hen s egg Its upper pole was rounded, on a level with the upper pole of the tonsil It did not affect the Eustachian orifice The lower end of the tumour was also rounded and extended to the level of the arytenoid region The mucosa on the tumour showed a coarse vascular pattern The consistency was firm and elastic the tumour was not definitely fluctuant and not tender

The right side of the neck revealed slight swelling but the tumour and the cervical lymph nodes could not be felt On pressure in the retromandibular space the pharyngeal tumour moved a little

The rest of the examination was non contributory

On the basis of the clinical examination a tentative diagnosis of a salivary mixed tumour or a branchiogenic cyst was made

Operation was performed under intubation anaesthesia and began with tracheotomy A Boyle–Davis gag was applied The tumour like cyst was well defined and could easily be dissected free from the lateral pharyngeal wall On the other hand, it was densely adherent posteriorly towards the spinal column Puncture of the cyst

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Voldgade 8, Sønderborg, Denmark

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BACTERIOLOGY AND PATHOLOGY OF CHRONIC MAXILLARY SINUSITIS

TAUNO PALVA, J. A. GRONROOS and ANTTI PALVA
Turku, Finland

From the Departments of Otolaryngology, Medical Microbiology and Pathological Anatomy, University of Turku

INTRODUCTION

Chronic maxillary sinusitis has been the subject of numerous investigations from both the bacteriological and pathological point of view. Various techniques have been employed to obtain a representative specimen of the secretion or pus in the maxillary sinus; it is now agreed that only specimens obtained directly from the antra can be considered free from meatal contamination.

Histopathological specimens have almost always been taken during the Caldwell-Luc operation from the thickened or polypous maxillary mucosa. Various staining techniques have been used to reveal the main changes, infectious or allergic, in the mucous membrane.

In this study we limited the examinations of bacteriological and pathological specimens to the cases of chronic maxillary sinusitis scheduled for a Caldwell-Luc procedure because of persistent suppuration of the sinus. Thus at operation we were able to collect both the bacteriological samples and the histopathological material straight from the opened sinus and so the former were free of any meatal contamination. Laboratory studies, viz. sedimentation rate and leucocyte count with differential analysis, were made together with an analysis of the protein content of the serum.

REVIEW OF LITERATURE

Seeing that during the period of this study (1958-60) a great variety of antibiotics were already available, it seems to suffice here to review only recent representative reports. For references in the older literature the reader is referred, for example, to the monograph of Björkwall on chronic maxillary sinusitis (1950).

The most important bacteriological findings in recent studies are summarized in Table 1. In all of them the specimen was taken through the antrum puncture needle; in some instances sterile physiological saline was instilled into the cavity before aspiration succeeded. In these latter cases there may sometimes be contamination with meatal bacteria if the saline is not immediately withdrawn but syringed back and forth.

A small number of staphylococci is obviously a good indication of a proper bacteriological technique, a low figure is reported by three of the authors reviewed here, viz. 4 % by Sparrevohn & Buch (1946), 0 % by Urdal & Berdal (1954) and 9 % by Björkwall. Somewhat larger percentages are given by van Dishoeck & Franssen (13 %) and Mounier-Kuhn (14 %). Piquet *et al.* report a high figure—31 %—but their series consists of long-standing cases. Urdal & Berdal specially claim that the staphylococci play no role in maxillary sinusitis.

Sparrevohn & Buch found that in acute cases pneumococci and in chronic cases hemolytic streptococci are the most frequent offending pathogens and that there generally is a mixed infection after two or three punctures. Urdal & Berdal, on the other hand, could not demonstrate any essential difference between the acute and chronic cases, their analysis also showed pneumococci to be the most frequent cause, followed by *Hemophilus influenzae*, while hemolytic streptococci played a minor role in the infections.

Björkwall's monograph, which is the most elaborate of the articles reviewed here, included also normal controls and correlation with the meatal flora. Healthy normal antra were sterile, the cases with purulent sinusitis showed most frequently hemolytic streptococci, followed closely by pneumococci, other bacteria playing a minor role. Among the 48 cases operated on, streptococci had been cultured in 50 %, pneumococci in 29 %, yellow staphylococci in 10 % and coliform bacilli in 23 %. It was suggested that if the corynebacteria, the normal inhabitants of the meatus, did not reappear during conservative treatment, the case was likely to lead to a radical operation.

Of the 67 cases subjected to bacterial analyses by Piquet *et al.* (1956) 31 % were sterile. Streptococci and staphylococci were the only pathogens in 42 and 31 % respectively, *Hemophilus influenzae* was found in one case, while pneumococci did not appear at all. The experience of Piquet *et al.* was that even these pathogens appear only in fresh cases: in chronic cases only saprophytic flora are encountered.

Another French study by Mounier-Kuhn (1953) showed the most frequent pathogens in 85 samples to be pneumococci, followed by various streptococci. Van Dishoeck & Franssen (1957) noted *Hemophilus influenzae* most often in 47 % of 215 samples, but the bacilli occurred in 63 % of the smears. Pneumococci appeared almost equally frequently, generally in combination with *Hemophilus*, while other bacteria played a minor role.

It is generally agreed that some apparently infectious cases prove sterile. If the maxillary secretion is mucous, it is generally sterile. Björkwall reported for these cases an incidence of 72 %. Other investigators do not draw a strict dividing line between cases with mucous and clearly purulent secretions. Sterile cultures were reported in 31 % by Piquet *et al.*, 34 % by Sparrevohn & Buch, 25 % by Urdal & Berdal and in clearly purulent cases in 14 % by Björkwall.

It is also noteworthy that in many instances the primary culture has shown

TABLE 1 *Bacterial analyses by different investigators*

Investigator	Number of sinuses	*Streptococcus viridans*	*Streptococcus β haemol*	*Streptococcus non haemol*	*Staphylococcus aureus*	*Staphylococcus albus*	*Diplococcus pneumoniae*	*Haemophilus influenzae*	*Escherichia coli*	Sterile	Other bacteria
Sparrevohn & Buch (1946)	100	90		2	4		11	7	0.5	34	Corynebact 4 %
Urdal & Berdal (1949)	81		8		0		39	31		25	Anaerobic 10 %
Bjorkwall (1950)	91	29		8	8	1	31	4	13	14	*Alcaligenes faec* 7 %
Mounier Kuhn (1953)	85		11	13	8	6	20	1	5	41	*Klebsiella pneum* 4 %
Piquet et al (1956)	47		43		31		0	1	10	31	Proteus 9 %, Neisseria 12 %
van Dishoeck & Franssen (1957)	215	136		13			49	47	5		*Neisseria catarrh* 14 %
Present study (1961)	86	30	2	3	4	3	10	11	3	38	*Alcaligenes faec* 10 %

a monoinfection Sparrevohn & Buch report it in 43 %. Monoinfection was also encountered by *Urdal & Berdal* in 50 % and by Bjorkwall in 65 % of the purulent cases. Mounier Kuhn reports it in 42 %.

Investigations into the cellular pattern of the maxillary secretion have not been usual. Van Dishoeck & Franssen report secretory eosinophilia in 90 out of 100 cases of allergic sinusitis, in another 100 cases without allergy eosinophils were only occasionally found.

Histopathological investigations have also shown tissue eosinophilia in stained sections. Van Dishoeck & Franssen report it in 75 % of 26 operated cases. Piquet *et al.* in allergic cases noted oedematous capillaries surrounded by histiocytes and eosinophiles.

Bauer (1960) observed in endoscopically obtained specimens that the eosinophilic cells were located immediately below the epithelium, only in long standing cases were there eosinophils in the deeper layers. According to him the basal membrane was characteristically thicker in allergic cases and there was tissue oedema.

The histological picture shows complete absence of eosinophilic cells in frankly purulent cases, which are characterized by dense neutrophilic and lymphocytic infiltration of the submucosa and mucosa. However Eckhoff

(1954) points out that it is often difficult to give a clear histopathological picture of any given case because there are many variations from field to field even in the same specimen

MATERIAL AND METHOD

The material includes 64 cases admitted to the hospital because of chronic maxillary sinusitis which did not heal with conservative treatment Age and sex classification of these cases appear in Table 2 The youngest patient was 14 years and the oldest 80 years of age There were 32 patients of each sex

In addition to the ordinary anamnestic and clinical data several other laboratory data were obtained These included sedimentation rate and complete blood cell analyses and in addition determination of the anti streptolysin (ASTO) and antistaphylolysin (ASTA) titers of the serum A sample of blood was also secured for electrophoretic serum protein analysis and for the total proteins

At the operation the contents of the maxillary sinus were aspirated into a sterile test tube which was transferred to the Department of Medical Microbiology, where analyses for bacteria were made A smear was also made for cellular studies and stained according to May–Grunwald–Giemsa Representative samples of maxillary mucosa were further secured, these were prepared at the Department of Pathology in the usual fashion and stained according to van Gieson and hematoxylin–eosin

The Biuret reaction was used for determination of the total serum protein The individual protein subgroups were determined using the method of paper electrophoresis Lissamine green was employed for staining the Joyce Loebl densitometer for drawing the curves on the basis of the staining intensity The individual albumin and globulin subfractions were calculated by copying the electrophoretic pattern first on thick smooth paper Vertical lines were then drawn from the minimum points of the curves towards the baseline for separating the different fractions from each other (albumin α_1, α_2, β, and γ globulins) The area determined by the baseline and the electrophoretic curve was then cut off and the different fractions were further separated by cutting along the vertical lines The pieces thus obtained were weighed with an accuracy of 0 1 mg the values obtained reveal directly the relative values of each fraction Knowing the total protein amount determined by the Biuret reaction the absolute values for each fraction can easily be calculated

The errors arising in this method are reasonably small A standard deviation of 6 % of the mean values was found when making 10 different measurements of one and the same basic curve

For bacterial analyses a slide stained by the Gram method was made of each specimen The specimens were cultured on blood agar and McLeod agar and inoculated into a liver broth tube The plates and the tube were incubated at 37 C The inoculated McLeod agar was kept in CO_2 atmosphere Plates which did not yield positive cultures after overnight incubation were incubated for another night The broth was considered negative if no growth occurred after an incubation time of one week

TABLE 2 *Age and sex classification*

	<20	21–30	31–40	41–50	>50	Total
Male	6	5	11	3	7	32
Female	1	8	6	5	12	32

The diagnostic tests used for identification of the micro organisms isolated were carried out according to the criteria published elsewhere (Gronroos, Palva & Saloheimo, 1957)

RESULTS

Clinical Findings

The present illness had lasted more than 6 months in the great majority of the cases, viz in 53 patients In 8 the sinusitis had lasted from 3 to 6 months, and in only 3 cases was the duration less than 3 months Of the latter, [illegible] were complicated by a dentogenous fistula following extraction of an infected tooth In 2 of the more chronic cases there was also a fistula of dental origin

The anamnestic data further revealed that 25 patients had a history of frequent other respiratory infections, including pneumonia in 10 cases Four of the patients had had Caldwell–Luc operations earlier, of which 2 were bilateral

Definite data regarding antibiotic treatment was obtained in 34 cases It appeared that 22 patients had received general antibacterial treatment at the beginning of the illness 16 received penicillin in doses of 600,000 units daily for [illegible] to 7 days in 9 of these latter other antibiotics were also tried without success Tetracyclines, chloramphenicol and sulpha were used in the rest of the cases In almost all cases, however, there was an interval of many weeks between the cessation of the antibiotic treatment and taking the bacterial specimens for the present study

In examining the patients attention was paid to possible anatomic alterations in the nose which might favour the development and chronicity of sinusitis A marked septal deviation to the right was noted in 15 and to the left in 3 cases Polyps occluding the middle meatus were found in [illegible] cases

Roentgen examination of the sinuses revealed a generally thickened mucosa sometimes forming a distinct polyp Others showed a fluid level or diffuse clouding of the antra In 15 cases the clouding extended to the ethmoid labyrinth and in 5 cases there were signs of frontal sinus involvement

Of the patients operated on 35 underwent a bilateral Caldwell–Luc procedure The 2 patients with a history of previous bilateral operation included one who had a revision the other was treated conservatively The 2 who had had a unilateral Caldwell Luc operation were now operated on the other side A total of 95 operations were thus performed

Of the unilateral cases 21 were on the right and [illegible] on the left side These data agree well with the findings as to septum deviation or polyps on the affected side

TABLE 3 *Leucocyte count and sedimentation rate*

Leucocyte count		Sedimentation rate/1 h	
Leucocytes	Cases	Sed rate	Cases
<8000	30	2–5	18
8000–15 000	31	6–10	18
15 000–20 000	1	11–20	15
Not studied	2	21–30	6
		31–60	4
		>61	3

The operation disclosed a mucosal cyst of 1 cm diameter or larger in 5 cases Both of the cases of dentogenous fistula still showed a root granuloma in the maxilla The granulomas were removed and closing of the fistula was done simultaneously with the Caldwell Luc procedure

Laboratory Data

The sedimentation rates and leucocyte counts appear in Table 3 The former are arranged by the scala of Leffkowitz (1937) and the latter according to the classification of Koskinen (1938)

In the majority of cases the sedimentation rate was low less than 21 in 51 cases In the group of over 60 mm/hour all the cases had chronic pulmonary inflammatory changes which were responsible for the high rate In the group of 31 60 mm/hour one patient had pulmonary tuberculosis and another a chronic nephritis which accounted for the high value In the two remaining cases and the whole group of 21 30 mm/hour the chronic maxillary sinusitis was the only disease to which the values could be attributed

About half of the cases had leucocyte values under 8000/mm³ which must still be considered normal In 31 cases the leucocyte count was clearly increased one case of recent pansinusitis showed a rise to 17 600

The differential blood count showed variations from strictly normal values in 42 cases thus there were 15 cases with altered relations between polymorphonuclear leucocytes and lymphocytes in either direction The basophilic and monocytic cells were at times slightly increased more seldom decreased below their normal values These changes cannot however be ascribed to sinusitis but rather reflect normal variations as well as changes seen in any chronic infectious process

The eosinophilic cells of the blood are interesting since the chronic maxillary sinusitis is frequently due to allergic factors or to a combination of allergy and inflammation In 10 of 62 examined slides there was an eosinophile count of 5 % or more In 2 cases it was over 8 % and the maximum was 18 % *These last cases with eosinophils exceeding 8 % definitely demonstrate the* allergic background of sinusitis trouble

The two cases with numerous eosinophilic cells in the peripheral blood

TABLE 4 *Results of electrophoretic analyses*

	Total	Albumin		α_1 glob		α_2 glob		β glob		γ glob	
	g%	g%	%	g%	%	g%	%	g%	%	g%	%
Normal values											
Mean	7 2	5 1	71 7	0 3	3 7	0 3	4 3	0 5	7 3	0 9	13 1
S D	0 4	0 3	3 7	0 05	0 6	0 07	0 9	0 08	0 9	0 2	2 6
Minimum value	6 3	4 6	63 0	0 2	2 9	0 2	2 8	0 4	5 6	0 6	9 6
Maximum value	7 9	5 8	75 4	0 4	4 8	0 5	6 5	0 7	9 0	1 5	20 0
Present material											
Mean	7 0	2 9	41 0	0 5	6 4	0 7	10 1	1 0	14 9	2 0	27 7
S D	1 0	0 5	5 5	0 1	1 7	0 2	2 3	0 2	2 0	0 5	4 9
Minimum value	4 [illegible]	1 7	28 6	0 1	2 8	0 3	4 7	0 5	10.8	0 7	12 8
Maximum value	9 5	4 7	54 7	0 8	10 4	1 2	18 4	1 5	20 0	3 1	40 4

suffered also from frequent asthmatic attacks The histological specimens from the maxillary sinuses showed a great increase of eosinophils accounting for 25 to 62 % of the inflammatory cells Among the 8 subjects with 5 to 8 % eosinophils in the differential blood count only one showed a noticeable increase of these cells in the histological specimen

To obtain a reference level for serum electrophoresis 22 normal young blood donors were subjected to an analysis with the method employed in the laboratory (Harri) These individual variations are shown in Table 4 where the obtained minimum and maximum values are given as percentages and in grams per cent These values correspond fairly well with the ranges obtained in normal material in other laboratories

In Table 4 (lower part) are given the results of the electrophoretic analysis in the present material The total protein values show some spread a few indicating hypoproteinemia The maximum value observed is 11 5 g%

The individual subgroups determined by paper electrophoresis show a clear deviation from the normal pattern Thus the amount of albumin is reduced 41 % as contrasted with 71 7 % in the normal material (standard error 0 8) Correspondingly the individual subgroups in the globulin fractions are higher than normal in the group of chronic maxillary sinusitis This is especially evident for γ globulins which show an increase to 27 7 % from the normal value of 13 1 %

Bacteriological Analyses

A total of 88 specimens were examined all taken under aseptic conditions from the maxillary cavity during the operation The occurrence of various bacteria in these specimens is given in Table 5

Monomicrobic infection was found in altogether 36 specimens two or more species were cultured from 19 specimens Thirty three specimens yielded no bacterial growth 15 of these were bilateral 5 showing bacteria on the other side

TABLE 5 *Results of bacteriological analyses*

Bacterial species	Number of sinuses
Streptococcus viridans	[illegible]
Hemophilus influenzae	10
Diplococcus pneumoniae	9
Alcaligenes faecalis	7
Staphylococcus aureus	4
Staphylococcus albus	3
Streptococcus non haemolyticus	3
Escherichia coli	3
Streptococcus β haemolyticus	2
Klebsiella pneumoniae	1
Klebsiella ozaenae	1
Citrobacter	1
Neisseria	1
Gram + coccus (negative culture)	1
Sterile	33

The bacteria most frequently encountered were *Streptococcus viridans* (30 %) *Hemophilus influenzae* (11 %) *Diplococcus pneumoniae* (10 %) and *Alcaligenes faecalis* (8 %) Other species were definitely less frequent

None of the isolated *Hemophilus influenzae* strains showed the iridescence phenomenon and were thus considered non encapsulated

The distribution of the types among the isolated Diplococcus strains was as follows

Number of strains	Type
3	IX
1	VI
1	XIX
2	XIX
2	Not typed

The isolated *Staphylococcus aureus* strains produced α toxin were coagulase and mannitol positive and liquefied gelatine

Sensitivity to the various antibiotics was tested in 82 instances The tests were made using antibiotic impregnated discs The result of these tests are indicated in Table 6 and classified as follows resistant 0 slightly sensitive + fairly sensitive + + and sensitive + + +

The table shows that the cocci were sensitive to antibiotics in most instances all strains were sensitive to chloramphenicol and to neomycin–bacitracin With one exception this applies also to the tetracyclines whereas both streptomycin and penicillin columns show many resistant strains The four *Staphylococcus aureus* strains for instance were all resistant to penicillin The same applies to sulpha drugs

Hemophilus influenzae strains were generally resistant to sulpha somewhat sensitive to penicillin and very sensitive to the other antibiotics tested The

TABLE 6. *Results of sensitivity tests*

	Sulpha				Penicillin				Streptomycin				Chloramphenicol				Tetracyclin				Neomycin + Bacitrasin			
	o	+	++	+++	o	+	++	+++	o	+	++	+++	o	+	++	+++	o	+	++	+++	o	+	++	+++
Streptococcus viridans	1		1	23	2	—	2	21	1	—	10	11	—	—	—	25	1	—	1	23	—	—	1	21
Streptococcus β haemolyticus	1		1	—	—		—	2	—	1	—	1	—	—	—	2	—	—	—	2	—	—	—	2
Streptococcus non haemolyticus		1	—	2		2		1	2	—	—	1	—	—	—	3	—	—	—	3	—	—	—	3
Staphylococcus aureus	1				1			—	1	—	—	1	—	—	—	1	—	—	2	2	—	—	—	1
Staphylococcus albus		1		2	1	—	1	1	—	—	—	1	—	—	—	3	—	—	—	1	—	—	—	3
Diplococcus pneumoniae			—	8	—	—	—	8	—	—	—	8	—	—	—	8	—	—	—	8	—	—	—	8
Hemophilus influenzae	1	—	1	1	1	1	2	1	—	—	—	8	—	—	—	8	—	—	2	6	—	—	—	8
Alcaligenes faecalis	3			1	7		—	—	6	—	—	1	—	3	—	1	3	3	—	1	—	1	2	1
Escherichia coli	1			2	1			—	1	—	—	2	—	1	—	2	1	—	1	1	—	1	1	1
Citrobacter	1				1	—		—			1	1	—	—	—	1	—	—	1	—	—	—	—	1
Klebsiella pneumoniae	—	—	1	—	1			—			—	1	—	—	—	1	—	—	—	1	—	—	—	1
Klebsiella ozaenae	—	—	1	—	1					—	—	1	—	—	—	1	—	—	—	1	—	—	—	1

remaining bacilli usually showed marked resistance to all other antibiotics except to chloramphenicol and to a neomycin bacitracin combination.

Of the 16 patients who had received penicillin earlier, 10 had a penicillin resistant strain in the antra, 3 of them being staphylococci. Among the remaining 6 cases the strain was penicillin sensitive in 3 cases and 3 specimens were sterile. Two patients had received tetracyclines: one specimen was sterile and the other showed *Diplococcus pneumoniae* sensitive to tetracyclines. Two patients had received sulpha and one patient chloramphenicol; in these cases the specimens were sterile.

Some combinations of antibiotics were also given, mainly streptomycin or sulpha with penicillin. Of these cases 3 of the specimens were sterile while the others showed either *Staphylococcus aureus* or resistant bacilli in the antra.

ASTO and ASTA

Antistreptolysin titers of the serum were determined in 60 subjects. Ten of these showed a value exceeding 400, a figure indicative of serological response to β hemolytic streptococci infection. However, the cultures from the antra revealed streptococci in only 2 instances; of the remaining 8 cases 5 were sterile while 3 specimens yielded *Diplococcus pneumoniae* and *Hemophilus influenzae*.

The antistaphylolysin titers exceeded 1.5 in 4 patients (1.6, 1.6, 2.0, 2.0), thus showing a serological response to Staphylococcus infection. *Staphylococcus aureus* was cultured from the antrum in one case, two were sterile and one yielded *Alcaligenes faecalis*. In two additional cases in which *Staphylococcus aureus* was cultured the ASTA figures were 0.22 and 0.32.

Histopathological Specimens

The specimens removed at operation were fixed in formalin and stained routinely by the van Gieson and hemotoxylin eosin. The principal findings in the 84 specimens studied are illustrated in Table 7.

The specimens were generally large, 1 to 2 cm in width. The histopathological changes did not show great variation in different parts of the specimen and the main histological classification could be made without much difficulty. In 56 specimens inflammatory cells appeared moderately or abundantly, while in 54 a marked oedema of the subepithelial tissue was noted. Some of the specimens showed pure characteristics of either type, in others a mixed picture prevailed. In the cases with pronounced oedema eosinophilic cells were seen in abundance in 24 specimens.

As the presence of thick mucopus in the antra was noted in most cases sheduled for surgery, special emphasis was paid to evaluating the amount of secretory glands in the mucosa. The specimens were obtained if possible from the bottom or lateral wall of the maxillary sinus which areas are normally poor in glands and not from the medial wall with rich glandular content (Bauer).

TABLE 7 *Main histological changes*

Classification	Number of specimens
Inflammatory cells	
Some	28
Many	45
Abundantly	11
Lymphocyte collections	45
Eosinophilic cells	26
Oedema	
Slight	30
Intense	54
Glands	
None or few	61
Abundantly	23
Fibrosis	
Slight	28
Moderate	40
Intense	16

In 61 specimens the microscopic examination showed a frequency and size of glands that must be considered normal In 23 cases there was a marked increase in the size of the glands which were often full of mucous or serous secretion If the edematous changes in the mucosa predominated the glands appeared in their normal surroundings in cases with marked chronic inflammatory reaction the glands were often separated from the direct subepithelial layer and from each other by heavy layers of fibrous scar tissue

In a considerable number of cases fibrous healing processes were going on the mucosa showing sometimes pronounced scarring Fibrous tissue was seen in moderate amounts in 40 specimens while in 16 it was very marked All the latter were cases with bilateral long standing processes

In 65 cases a smear was made of the antral mucus contents and stained after May–Grunwald Giemsa In studying these slides the main emphasis was placed on two elements viz neutrophilic leucocytes and eosinophilic cells The former appeared in large numbers in 17 specimens and the latter in 7 In other slides various cellular elements were seen but their occurence did not seem to be of great significance In most slides there appeared large amounts of thick sticky mucus which together with the admixture of blood made evaluation of the slides somewhat difficult

DISCUSSION

The sedimentation rate is only moderately increased when sinusitis is under treatment A high sedimentation rate can be found in cases with

Fig 1 Normal mucosa from the lateral wall of a healthy maxillary sinus The epithelium is intact, the subepithelial layer thin and devoid of cells, and glands are absent Magnification ×130

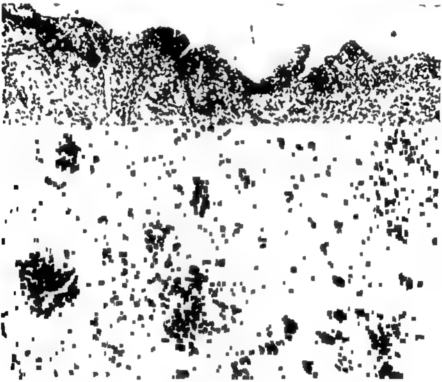

Fig 2 Numerous lymphocytic follicles in a moderately inflamed mucosa Magnification ×50

frank pus in the antra in the subacute cases, mainly in the form of pansinusitis, in chronic maxillary sinusitis some other cause [illegible] as rule responsible for rates of over 50 mm/hour

The leucocyte count is moderately increased in chronic cases This seems to be a clear response of the organism's struggle against infection, and likely to contribute in most cases to eradication of the disease

The differential blood count does not seem to offer much help in the evalua

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Fig 3 Mucosa from maxillary sinus of an allergic patient There are goblet cells in the epithelium, the basal membrane is thick and the subepithelial tissue loose and oedematous The few cells consist mainly of eosinophilic cells Magnification ×50

Fig 4 Fibrous mucosa The subepithelial layer consists of fibrous tissue, some glands and a small amount of inflammatory cells The number of arterioles is fairly large Magnification ×50

tion of these cases. An increase in the number of eosinophils would be of a great importance if it were present in all cases in which allergic factors play a role. Unfortunately the peripheral blood picture is not often helpful in this respect, although in some cases there is a great number of eosinophilic cells.

The electrophoretic analysis of the serum protein shows some interesting features in chronic sinusitis. In 4 cases the total protein was less than 5.5 g% and thus clearly below normal. This fact is likely to cause lowering of the resistance to infection and it is understandable that the maxillary sinusitis became chronic. However, it must be remembered that the values for total serum protein were within normal limits in the large majority of patients and a lowered protein cannot thus account for the chronicity of the infection.

On the other hand, the protein subgroups show a clearly abnormal composition, the albumins being reduced and the globulins increased. The increase is especially noted in γ globulins, which are known to play an important part in the body's fight against infection. This trend of increased γ globulins was obvious in all cases studied and the difference from the normal controls is clear cut.

It is well known that cases of agammaglobulinemia and even cases with hypogammaglobulinemia are particularly prone to infection of the upper respiratory tract and that in these cases the administration of γ globulin intramuscularly is of the greatest importance. In this series we rather expected to find some cases in which especially the γ globulins would be reduced, but this expectation was not fulfilled. On the contrary, the reverse was true, which is definite evidence of the active role played by the host in combating infection.

Similar findings in ozaena have been reported by Bedoni & Corbetta (1959). Their studies on 12 ozaena patients revealed hypoalbuminemia and hypergammaglobulinema as a constant finding.

The results of the bacterial analyses must be weighed against the fact that the specimens were taken after many punctures, in some cases after earlier antibiotic treatment, and in almost all cases after local instillation of penicillin into the antra. Also the body's own immunological response by secretion of bactericidal substances into the antra in infections of longer duration would make many secretions sterile. This applies especially to *Diplococcus pneumoniae*, β hemolytic streptococci and *Hemophilus influenzae* species, which are frequent in most specimens taken at the beginning of the infection.

It is noteworthy that monoinfection prevailed even in these long standing cases in 41 %, while 38 % were sterile. Mixed infections, which are thought to appear in chronic cases as a rule, formed here a small group.

β hemolytic streptococci, which were quite frequent in some materials presented in Table 1, occurred in only 2 cases (2 %). Other streptococci, mainly the viridans type, were the most frequently isolated bacteria (30 %). Then followed *Hemophilus influenzae* (11 %), *Diplococcus pneumoniae* (10 %) and *Alcaligenes faecalis* (10 %).

Staphylococcus aureus appeared in the series in 4 cases (5 %)—a figure further supporting the fact that the larger percentages sometimes reported are mainly due to contamination from the nasal meatus.

The lack of capsule in the *Hemophilus influenzae* strains must be interpreted as indicating a low virulence: strains of this type are frequently found in the normal upper respiratory tract.

Among the *Diplococcus pneumoniae* types isolated, IV and VI belong to the group of relatively few types which are responsible for most cases of lobar pneumonia, whereas types XIV and XIX (beside I and VI) most often cause lobar pneumonia in children. All the isolated Diplococcus strains are thus associated with virulent infections.

The yellow staphylococci isolated showed all characteristics of pathogenic staphylococci. The ASTA reactions were 1.6 and 2.0 in two of these cases; in the other two they were below 0.5.

The sensitivity tests to various antibiotics showed that in the acute stages of the disease penicillin generally can be given with advantage. This is especially true of *Diplococcus pneumoniae* and *Streptococcus β hemolyticus* infection and to a limited extent of the third common bacterium *Hemophilus influenzae*. In this connection it should be pointed out that the sensitivity to penicillin was shown to penicillin G only. Of the different penicillins at present available the sodium G penicillin is the most effective against Hemophilus infections, whereas the others have almost no effect (Garrod 1960). In the latter stages, when the bacterial flora changed markedly from the days of the acute onset, chloramphenicol is most often effective against various invaders. However, bacterial analysis and sensitivity tests are the best guide in determining the proper drug.

While the vast majority of the cases heal well and rapidly with this regimen there are cases in which the antral lavages have to be continued week after week without clearing of the washouts. This may be due to several causes: we have already noted that impaired drainage due to septal deviation or polyps in the middle meatus are contributing factors. However, it seems that in most cases the mucosa in the maxillary sinuses and in the closely adjoining ethmoidal cells in the roof of the antrum become chronically infected, polypous and partly fibrous and that the antibiotics do not reach the bacteria harboured by the mucosa. Further, if the mucosal lining undergoes severe inflammatory changes which result in a greatly deformed mucosa with low resistance, the infectious process is not likely to be easily conquered and the bacteria generally present as saprophytes in the upper respiratory tract can invade the diseased sinus. Lastly, there certainly are allergic changes in some mucosal linings which render it more susceptible to chronic symptoms.

These ideas are supported by the examination of large pieces of tissue removed from the antra. Macroscopically some antral linings are over one centimeter thick, polypous, sometimes with intramucosal abscesses seen by the naked eye. In the microsopic sections the mucosa is seen to be invaded by inflammatory cells, with areas of small abscesses and sometimes showing

extensive scarring with trapped infective areas in between In these cases the examiner feels that his Caldwell-Luc approach has been fully justified and that the patient is well rid of this tissue in the antra On the other hand there appear a few specimens with rather slight changes in the mucosa mainly consisting of loose oedematous tissue with only a limited amount of infectious elements In these cases one wonders whether it has been wise to remove the mucosa if the principal changes are traced back to allergy and not to any real infectious process

In purely allergic rhinitis the antra remain clear and there is no need to consider operation because of running noses Our operated cases showing also allergic signs in the mucosa were primarily complicated by a superimposed bacterial infection We made it our policy that if the weekly antral punctures and at least two 1 week courses of antibiotics did not result in cure of the sinusitis within 8 weeks the patients were advised to return to the hospital for a Caldwell-Luc procedure

We feel however that until maxillary sinusitis in allergic patients can better be treated with medical means than is possible at the present time the Caldwell Luc approach is justified if repeated lavages return a positive washout In these cases we do not insist on removing the mucosa except in definitely thick and polypous areas A Caldwell-Luc approach allows a very large opening to be made in the inferior meatus which is essential for good healing and gives one a chance of minute inspection of the antral cavity These are such great advantages that we only very seldom use the endonasal antrum window technique in adult cases

SUMMARY

This report is a presentation of the results in clinical bacteriological and histopathological studies of 64 patients upon whom 95 Caldwell Luc operations were carried out because of chronic maxillary sinusitis The sedimentation rate was usually below 50 mm/1 hour and the leucocyte count only moderately increased The differential count for eosinophilic cells did not prove helpful as only 2 patients had a value of 8 % or over In serum electrophoresis the total protein was mostly within normal limits but the globulins were clearly increased and the albumins decreased

Streptococcus viridans was the organism cultured most frequently (30 %) next followed *Hemophilus influenzae* (11 %) *Diplococcus pneumoniae* (10 %) and *Alcaligenes faecalis* (8 %) Yellow staphylococci were found in 4 % and other species less frequently Antistaphylolysin titers were increased above 1 5 in 4 cases antistreptolysin O titers were over 400 in 10 cases indicating the active role played by the β hemolytic streptococcus during the early stages of the disease

In histopathological specimens inflammatory changes were most prominent and then followed allergic oedemic changes Mixed types were also seen as well as heavily scarred fibrotic mucous membranes Various lines in treatment are discussed on the basis of mucosal pathology

ZUSAMMENFASSUNG

Vorliegender Bericht behandelt die Ergebnisse klinischer, bakteriologischer und histopathologischer Untersuchungen bei 64 Patienten, an denen 95 Caldwell Luc Operationen wegen chronischer Sinusitis maxillaris vorgenommen wurden Die Sedimentierungsrate lag im allgemeinen unter 50 mm pro Stunde, und die Anzahl der Leukocyten nahm nur massig zu Der Differentialwert fur Eosinophile Zellen erwies sich als nutzlos, da nur zwei Patienten 8 % oder daruber zeigten Bei Serum-Elektrophorese hielt sich die Gesamtproteinmenge grösstenteils innerhalb normaler Grenzen, aber die Globuline hatten deutlich zugenommen und die Albumine abgenommen

Streptococcus viridans war der am haufigsten auftretende Organismus (30 %), dann folgte *Haemophilus influenzae* (11 %), *Diplococcus pneumoniae* (10 %), und *Alcaligenes faecalis* (8 %) Gelbe Staphylococci wurden bei 4 % gefunden und andre Arten noch seltener Antistaphylolysin Titres lagen in 4 Fallen uber 1,5 Antistreptolysin O Titres uberstiegen 400 in 10 Fallen, was die aktive Rolle des β haemolytischen Streptococcus im Fruhstadium der Krankheit anzeigt

Histopathologische Proben zeigten in erster Linie inflammatorische Veranderungen und dann folgten allergische, oedemische Veranderungen Gemischte Typen traten ebenfalls auf, sowie stark vernarbte, fibrose Schleimhaute Verschiedene Behandlungsarten werden auf schleimhaut pathologischer Grundlage erörtert

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Kaskenkatu 4b, Turku

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THE BASAL ANGLE IN THE CLINICAL DIAGNOSIS OF OTOSCLEROSIS

PEKKA VUORINEN and OTTO H. MEURMAN
Turku, Finland

From the Oto-Rhino-Laryngologic Clinic (Head: Prof. O. H. Meurman) University of Turku

In a study of human skulls Sercer stated that changes may occur in the form of the base of the skull which may be responsible for the development of otosclerosis. The size of the sphenoidal angle was, he said, an indicator of these changes and might be useful in the clinical diagnosis of otosclerosis. *In order to confirm this theory, the sphenoidal angle was measured from* lateral skull roentgenograms of 25 patients suffering from otosclerosis and 105 control patients with a skull injury. No significant difference was found in the mean sphenoidal angles of the two groups nor was there any correlation between the size of the sphenoidal angle and the age of the patient in either group. The theory could thus not be confirmed and it was concluded that the sphenoidal angle cannot be employed as a criterion in the clinical diagnosis of otosclerosis.

In a study (1958) of the anthropological factors influencing the growth and changes in form of the human skull, Sercer states that mechanical factors play a role in the aetiology of otosclerosis. According to his investigations, the posture of man causes alterations in the form of the base of the skull during the early years of life up to the age of puberty. He supports this theory by the observations that in quadrupeds the base of the skull is normally in a vertical position or close to the vertical, that animals do not have otosclerosis, and that the form of the base of the skull differs in children and adults. He proved the latter by comparative measurements of 343 human skulls.

The form of the base of the skull can be defined by the *sphenoidal angle* (Welcker) (Testut 1896). This angle is the angle formed by a line connecting the nasion (which is the median point of the nasofrontal suture) to the middle point of the sella turcica and another line running from the basion (median anterior margin of the foramen magnum) to the middle point of the sella turcica (Lindgren 1954). This angle is shown in the schematic drawing in Fig. 1.

The sphenoidal angle can be measured from lateral skull roentgenograms (Koski 1960, Lindgren 1954). Sercer concluded from a study of clinical material that a large sphenoidal angle (for instance 130°) argues against the presence of otosclerosis, whereas a small angle (for instance 108°) is sug-

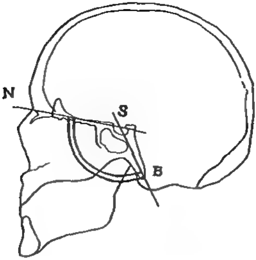

Fig. 1. Schematic drawing showing how the sphenoidal angle is measured. It is the angle between lines connecting the nasion (N) with the sella turcica (S) and the sella with the basion (B) and it can be measured from lateral skull roentgenograms.

gestive of the disease. Sercer does not disclose the number of his clinical patients or any other facts from his clinical experience, nor does he give limiting values for a "large" or a "small" sphenoidal angle, but states that this angle is not a reliable criterion in an individual patient.

If a small sphenoidal angle is correlated with the occurrence of otosclerosis

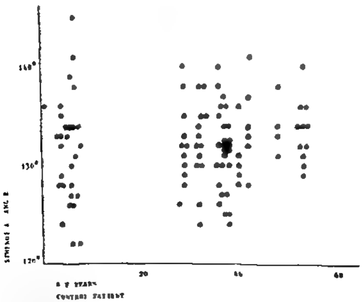

Fig. 2. Scatter diagram showing the distribution of the measured values of the sphenoidal angle in the control (traumatic) group of patients plotted against their age. There is no correlation between the age and the sphenoidal angle.

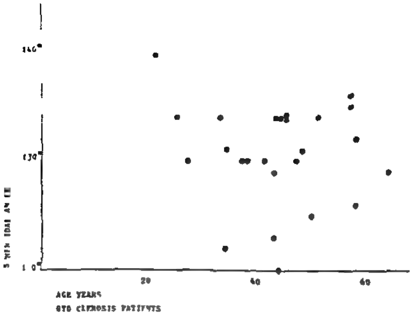

FIG 3 Another scatter diagram showing the sphenoidal angles of the otosclerosis group plotted against the age of the patients There is no correlation between the age and the sphenoidal angle nor is there any essential difference in the distribution of the measured angles between the two diagrams in Figs 2 and 3

it would be a valuable aid in the clinical diagnosis of this disease The purpose of this investigation was to try to confirm Sercer s results in a clinical material by determining

(1) whether the sphenoidal angle is significantly smaller in patients suffering from otosclerosis than in normal controls and

(2) whether the sphenoidal angle decreases with increasing age up to puberty

MATERIAL

Our otosclerosis material consisted of 25 patients who had a clinically diagnosed otosclerosis and who had all been operated upon The diagnosis had thus been verified beyond doubt in every case

The control material consisted of 108 unselected patients who had had a roentgenologic examination after a head injury Most of them had suffered a cerebral concussion but some had suffered also a skull fracture These had not however caused any deformation of the base of the skull None of the patients were known to have had any previous neurologic or otologic disorder Three patients were excluded from the control group owing to an abnormal form of the skull (oxycephaly)

The sphenoidal angle was measured from the lateral skull roentgenograms of the patients The films were taken with a focal distance of 100 cm with the

subject lying on an ordinary Bucky couch The same technique was employed in all cases

The necessary points the nasofrontal suture the sella and the foramen magnum were fairly clearly visible on the films and there was no difficulty in drawing the necessary lines on the films The sphenoidal angle was measured to the nearest degree Slight variations in the measured angles may have been due to the fact that all the roentgenograms were not exactly lateral since a special skull table or craniostat or any other additional device was not used

RESULTS

The mean value of the sphenoidal angle was 130 6° for the otosclerosis group and 132 1° for the control group Thus there was a slight difference between the mean values for the two groups As the statistical probability of being in error is between 5% and 10% the difference cannot be considered significant Further data are shown in Table 1

As the mean values of the groups were not significantly different it is not possible to draw any conclusions from the measured value of the sphenoidal angle of individual patients The range of measured sphenoidal angles was 120 to 139° in the otosclerosis group and 122 to 145° in the control group The sphenoidal angle is therefore of uncertain value in the clinical diagnosis of otosclerosis Not a single patient had a sphenoidal angle as small as the 108° found by Sercer in one patient

Another aim of the present study was to investigate the correlation between the age of the patient and the sphenoidal angle The measured values of the sphenoidal angle are plotted against the ages of the patients of the two groups in Figs 2 and 3 The sphenoidal angle is seen to be independent of the age of the patient this was confirmed by a statistical calculation of the correlation coefficient If the statement of Sercer that the form of the base of the skull changes in a growing individual were correct the sphenoidal angle should change There should certainly be some difference between a group of patients up to 10 years of age and a group of patients between 30 and 50 years of age We did not find any difference This result is consistent with the results of Koski who did not find any significant differences in the sphenoidal angles in a group of 330 patients between the ages of 7 and 22 years (Koski 1960)

TABLE 1 *Comparison of the statistical data for the measured values of the sphenoidal angle in the (traumatic) control group and in the group of patients suffering from otosclerosis*

	Normal	Otosclerosis
Number of patients	10	[illegible]
Sphenoidal angle mean	132 1	130 6
S E of the mean	0 43	0 9
S D of observations	4 4	4 6

ZUSAMMENFASSUNG

Bei einer Untersuchung von menschlichen Schadeln stellt Sercer fest, dass Veranderungen in der Form der Schadelbasis vorkommen konnen, die fur die Entwicklung von Otosklerose verantwortlich sein konnen. Die Grosse des Sphenoidalwinkels solle diese Veranderungen anzeigen und konne bei der klinischen Diagnose der Otosklerose herangezogen werden.

Um diese Theorie zu prufen wurde der Sphenoidalwinkel an seitlichen Rontgenbildern des Schadels von 25 Patienten mit Otosklerose und 105 Kontrollfallen mit Schadelverletzungen gemessen. Es wurden weder deutliche Unterschiede zwischen den Mittelwerten des Sphenoidalwinkels der beiden Gruppen gefunden, noch bestand irgendeine Korrelation zwischen der Grosse des Sphenoidalwinkels und dem Alter der Patienten der beiden Gruppen.

Die Theorie konnte somit nicht bestatigt werden und man kam zu dem Schluss, dass der Sphenoidalwinkel nicht als Kriterium bei der klinischen Diagnose der Otosklerose herangezogen werden kann.

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University Central Hospital, Turku

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THE MECHANISM OF NYSTAGMUS

ERIK FLUUR
Stockholm, Sweden

From the Department of Otolaryngology (Prof. C. A. Hamberger), Karolinska Sjukhuset, Stockholm 60

In six persons with spontaneous vertical nystagmus behind closed eyes concurrent horizontal nystagmus was induced by caloric irrigation of the horizontal semicircular canals in the vertical position. This procedure caused no change in the vertical nystagmus pattern. When the horizontal nystagmus subsided the number of eye movements decreased, whereas the vertical nystagmus continued unchanged. The rapid phases of horizontal and vertical nystagmus invariably coincided even if the two types otherwise differed in frequency.

The mechanism eliciting nystagmus is discussed, the following conclusions being drawn: (1) the slow phase of horizontal and vertical nystagmus is controlled from separate independent centers; (2) the rate of the slow phase is influenced by both peripheral and central factors; (3) the rapid phase is elicited from a center common to horizontal and vertical nystagmus; (4) the mechanism of nystagmus is controlled from the extraocular muscle nuclei but may be affected by various centers.

The mechanism controlling normal eye movements is rather complex. The movements of each eye are produced by six extraocular muscles, each of which receives impulses from various sources and via different pathways; moreover, the two eyes have to be precisely co-ordinated in their movements. The investigations of Szentágothai (1943), among others, have shown that this co-ordination is controlled from centers which have a supranuclear localization in relation to the extraocular muscle nuclei. From frontal, occipital, and vestibular centers, pathways run to one such center in nucleus interstitialis of Cajal for vertical and rotary movements of th[illegible] and to another one in the mesencephalic reticular formation f[illegible] movements. These two centers apparently function quite indepen[illegible] each other, as evidenced by both clinical and experimental inv[illegible] (Bremin & Moldaver 1955, Moldaver & Bremin 1956, Fluur [illegible]).

Nystagmus consists of a slow movement of the eyes from th[illegible] tion, followed immediately by a rapid return to the initial po[illegible] movement can be elicited from one of the above-menti[illegible] question as to which center is responsible for the rapid [illegible] the other hand, has long attracted considerable attention.

Several authors have held the view that the rapid phas[illegible] peripheral labyrinth. Maupetit (1908) believed that it [illegible]

whereas in the opinion of Rejtoe (1920) the reaction was produced from the maculae. The latter theory is disproved by results obtained after experimental destruction of the labyrinthine function.

Other workers propounded a peripheral ocular theory according to which the contraction of the eye muscles stimulates the proprioceptive nerve terminals in the respective muscles, thereby affecting the activity of the nuclei, via the trigeminus, in such a way as to elicit the rapid phase (Bartels, 1910, 1912, Brunner, 1919, 1924, Marburg, 1924, 1926). De Kleyn (1921, 1939) shattered this theory, however, by injecting procaine into the eye muscles and still eliciting nystagmus.

Bartels (1910) put forward a cortical theory on the basis of his observations that the rapid phase is absent in unconscious persons. He assumed that the impulses which elicited this phase stemmed from the eye muscles, whence they were transmitted to the cortex. In the opinion of Rosenfeld (1911) a special cortical center for the rapid phase existed in the frontal lobe. The untenability of this theory is demonstrated by the well known fact that nystagmus can be induced even in decerebrate animals.

Numerous workers have assumed that the rapid nystagmus movements are elicited from subcortical centers. Wernicke (1889), for instance, thought this center was situated in the nucleus abducens, Monakow (1914) was of the view that it lay in the region of the aqueduct of Sylvius, while Spitzer (1924) localized it to the diencephalon, and Lorente de No (1928) believed it to be located in the reticular formation. Szentágothai conducted several admirable investigations into the oculomotor reflex mechanism. He found (1943) in the midbrain several points from which excitation or reciprocal inhibition of extraocular muscles could be elicited. In a subsequent study (1950) he demonstrated that "stimulation of the anterior midbrain central gray matter" resulted in "simultaneous relaxation of several extraocular muscles". Szentágothai & Schab (1956), with the aim of studying the manner in which stimulation of this area influenced the effect of labyrinthine impulses on the extraocular muscles, conducted an investigation which showed that when one of the semicircular ducts (right posterior ampulla) was stimulated concurrently with the above mentioned area—which proved to be the nucleus of Darkschewitsch—the activity was immediately abolished in those eye muscles which had been contracted by the vestibular stimulation. No results dealing with concomitant stimulation of Darkschewitsch's nucleus and the horizontal semicircular canal were reported. Since Darkschewitsch's nucleus and the interstitialis nucleus of Cajal are contiguous to each other, the former might be assumed to be an inhibitory center merely for the latter, which receives its impulses precisely from the posterior vertical semicircular canal. The authors, however, concluded their article with the words: "It is highly probable that inhibition of motor ocular neurons in general is brought forth by the activity of this group of neurons."

Since it has not been conclusively established whether the rapid nystagmus phase, like the slow one, is individual for horizontal and vertical nystagmus

FIG 1 Horizontal nystagmus (upper curve) following caloric irrigation in a subject without spontaneous vertical nystagmus (lower curve) behind closed eyes

or whether it is common to both it was considered worthwhile to study this problem in patients who had normally manifested vertical nystagmus on closing their eyes (Huur & Eriksson 1961)

Methods

Six persons with spontaneous vertical nystagmus behind closed eyes were subjected to caloric tests *ad modum* Fitzgerald & Hallpike (1942) The examinations were made with the patients recumbent and their horizontal semicircular canals in the vertical position Horizontal nystagmus was recorded by means of electrodes placed in the outer canthus of each eye while for examination of vertical nystagmus electrodes were placed above and below the eye on the vertical line through the pupil in forward gaze The recorder was a four channel nystagmograph (Schwarzer)

In order to ascertain if the method employed also gave rise to endolymph currents in the vertical semicircular canals similar experiments were conducted on two persons who had no vertical nystagmus behind closed eyes

In evaluation of results the frequency and amplitude of the vertical nystagmus were invariably compared both before and during the caloric tests In addition comparisons of the simultaneously recorded horizontal and vertical nystagmus curves were made

Results

The subjects without spontaneous vertical nystagmus behind closed eyes presented at the caloric tests no signs of endolymph currents giving vertical nystagmus They did however exhibit horizontal nystagmus which was bilaterally equal in intensity and duration (Fig 1)

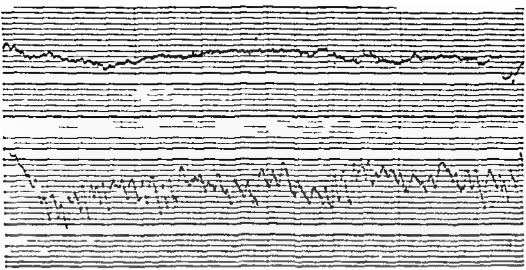

Fig 1 Spontaneous vertical nystagmus upward (lower curve) in a subject with eyes closed There are no horizontal movements of the eyes (upper curve)

The vertical nystagmus behind closed eyes in the remaining six subjects exhibited certain spontaneous variations in both frequency and amplitude (Fig 2) It was characteristic of these patients however that when horizontal nystagmus was likewise induced by vestibular stimulation no change occurred in the basic pattern of the vertical nystagmus curve (Fig 3) Although minor amplitude fluctuations were discernible they were not constant but variable in any single subject both during one examination and from one examination to another At times a lower amplitude was obtained and at times a somewhat higher amplitude while on one occasion there was no change whatsoever

In the initial phase of the recording the two nystagmus curves were sometimes more or less synchronous in frequency When the horizontal nystagmus then began to subside one of the manifestations was a decreased number of movements per unit time (5 seconds) At the same time the vertical nystagmus continued with the same frequency throughout An interesting observation was that the rapid phases of horizontal and vertical nystagmus always coincided irrespective of whether the two types otherwise differed in frequency (Fig 3)

DISCUSSION

The electronystagmographic recording method may seem unsatisfactory for concurrent studies of movements in both the x and the y axes The eye is of course an electrical dipole moving along two co ordinates horizontally and vertically If two independent forces act simultaneously upon a mass—in this case the eye—in axes perpendicular to each other there will arise a parallelogram of forces in which the mass will move in the direction of the

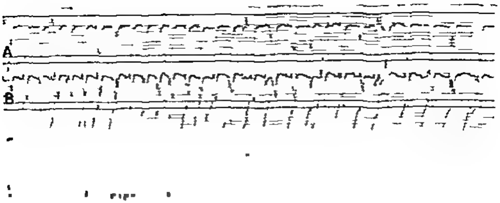

FIG. 3. Horizontal nystagmus (*C*) following caloric irrigation in a subject with spontaneous vertical nystagmus (*D*) behind closed eyes. A and B indicates the concurrence of the fast phases of horizontal (A) and vertical (B) nystagmus.

resultant. A diagonal movement of the eye will thus occur, though it will be a secondary result of the influence of the two co-ordinate forces. There is no known center capable of initially producing diagonal eye movements. Since the spontaneous vertical nystagmus remains unchanged even if horizontal nystagmus is simultaneously induced by vestibular imbalance, the implication is that the electronystagmographic recording method makes possible a *division of the resultants into these two components* without distortion of the curves.

The individual nystagmogram expresses a movement in time along two axes, the constant paper speed representing the *x* axis and the lateral movement of the eye the *y* axis. The velocity of this movement is reflected both in the level of the curve and in its angle with the horizontal plane. Meticulous study of the curves shows, moreover, that the rate of the slow phase is unchanged throughout in vertical nystagmus, whereas it continuously diminishes in horizontal nystagmus as a result of the declining frequency of impulses from the horizontal semicircular canal. These findings suggest that the *slow* phases of horizontal and vertical nystagmus are quite independent of each other, as has already been pointed out by other authors.

Comparison of the vertical and horizontal nystagmus curves indicates that the numbers of nystagmus movements per five seconds nearly always differ in the *x* and the *y* axes, but that the rapid phase of horizontal nystagmus is invariably synchronous with the same phase of vertical nystagmus, even though the latter shows a considerably greater number of movements over the same period. This finding suggests that the *rapid* phase, in contrast to the *slow* phase, is elicited from a center which is common to both forms of nystagmus, and thus *corroborates the assumption made by* Szentágothai & Schaib (1956).

By comparing the horizontal and the vertical curves while the horizontal component is subsiding, it is possible to gain some idea of the functioning

of this suppressor area, the action of which gives rise to the rapid nystagmus phase. Whilst the horizontal curve exhibits a lower amplitude and fewer movements per five seconds, the vertical nystagmus continues unchanged. On occasion, several rapid vertical movements may occur before a horizontal movement can be detected. This phenomenon can be explained in terms of an analogous mechanism which exists in the ventral horn cells of the spinal cord (Granit 1961). The ability of a synapse to transmit electrical impulses is dependent on three factors. Neurophysiologic determinations have shown that there exists, at rest, a potential difference amounting to −50 to −80 mV between the sheath and the interior of the nerve. The sheath has a positive charge in relation to the negative interior. When the synapse transmits an impulse to the next nerve, it takes place via a discharge or depolarization, which implies that the negative potential difference of −50 to −80 mV at rest is broken down and may even change to positive. When the impulse has passed, the polarity is once more built up to values which, as a rule, momentarily exceed those at rest. This phenomenon is known as hyperpolarization. Now there exist special nerve fibers which pass to the synapse and which come either from other nerve cells in the vicinity or from higher centers. These nerve fibers have, by virtue of their activity, the ability to raise the polarity or the potential difference between the sheath and the interior of the nerve, the result being an increase in the conduction threshold of the impulses. In this way these fibers come to act as inhibitors of the synaptic capacity to transmit signals between the two nerve fibers. Hence the function of the synapse is constantly dependent upon that impulse frequency or that polarization pressure which, in the given case, exists on either side of the resting state. If the depolarization pressure is high and the hyperpolarization pressure low, the result will be a depressed threshold and facilitation of the impulse propagation. If, on the other hand, the hyperpolarization pressure is high, there will be more or less complete inhibition of all signals. The threshold will be almost limitless.

This process in the spinal cord has been called recurrent inhibition. *Eccles, Fatt & Koketsu (1954)* and *subsequently Brooks & Wilson (1959)* and Wilson (1959) demonstrated that it is due to hyperpolarization. Granit & Rutledge (1960) made a quantitative estimate of its influence on the reflex action of motoneurons in the spinal cord. They showed that recurrent inhibition is on the whole constant as long as there is an excess of impulses to depolarize the synapse, but that the inhibition increases as the excess of impulses falls. The aforementioned investigation conducted by Szentágothai & Schab (1956) showed that Darkschewitsch's nucleus contains nerve cells which, on activation, cause inhibition in the nerve fibers passing to the extraocular muscles. It is highly probable that this inhibitory mechanism is attributable to hyperpolarization of the synapses in the oculomotor centers.

The probable explanation of the observed difference in the number of horizontal and vertical nystagmus movements is that with a decline of impulse frequency the depolarization pressure elicited via the vestibular apparatus in

the horizontal eye movement control center in the reticular formation becomes increasingly unable to break down that hyperpolarization pressure to which the oculomotor centers are constantly subject. The variable level of the different nystagmus movements suggests that even the slow phase is dependent not only upon the vestibular depolarization pressure but also upon that hyperpolarization pressure which may exert from the nucleus of Darkschewitsch an inhibitory effect on impulse propagation.

The investigation has led to the following conclusions:

1. In simultaneous horizontal and vertical nystagmus the slow phases are controlled from separate independent centers.
2. The rate of the slow phase is dependent not only upon the vestibular impulse frequency but also upon the action of central inhibitors.
3. The rapid phase appears to be elicited from a center common to both horizontal and vertical nystagmus.
4. The mechanism of nystagmus seems to be largely the concern of the extraocular muscle nuclei though it may be affected by several different centers.

ZUSAMMENFASSUNG

An sechs Personen mit spontanem vertikalen Nystagmus wurde gleichzeitig einen horizontalen Nystagmus durch kalorische Spülung von den horizontellen Bogengängen in vertikaler Stellung induziert. Dieses führte keine Veränderung in das vertikale Nystagmusbild mit. Während des horizontalen Nystagmusabklanges verminderte sich die Anzahl der Ausschläge, wogegen der vertikale Nystagmus unverändert fortsetzte. Die schnelle Phase kam immer gleichzeitig sowohl in horizontalem als auch vertikalem Nystagmus, unberuhend davon daß die beiden Typen im Übrigen verschiedene Geschwindigkeiten untereinander hatten. Der Auslösungsmechanismus des Nystagmus wurde diskutiert. Folgende Schlußsätze sind gezogen:

Die langsame Phase des horizontalen und vertikalen Nystagmus ist von verschiedenen voneinander unberuhenden Zentren reguliert.

Die Geschwindigkeit der langsamen Phase ist sowohl peripher als zentral beeinflusst.

Die schnelle Phase ist für sowohl horizontal als auch vertikal Nystagmus gemeinsam.

Der Nystagmusmechanismus wird von den Augenmuskelkernen gesteuert, aber kann von verschiedenen Zentren beeinflusst werden.

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Dept of Otolaryngology, Karolinska Sjukhuset, Stockholm 60

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A NEW TYPE OF HAND KNOBS FOR THE SURGICAL MICROSCOPE

OLLE HALLEN

Departments of Histology and of Oto-Laryngology, University of Goteborg, Sweden

Without doubt it can be said that the firm of Carl Zeiss has made a great contribution to the development of modern otomicrosurgery by the design and construction of the surgical microscope. The major reason for this instrument's good reputation lies in its unique combination of centered illumination, large working distance and good magnification optics. The instrument is used today by otologists all over the world.

Particularly during transmeatal operations the otologist is forced to work within a very small surgical field. In spite of the outstanding design of the microscope, such an operation demands repeated readjustments of the instrument. These include focussing, changes in magnification and reorientation of the instrument. In order to facilitate manipulation of the instrument new hand knobs have been constructed which make possible the three types of adjustment with only a slight change of grip.

The hand knobs are machined in light metal (Fig. 1) and fit the standard hand knobs of the microscope. They are fixed by three set screws, two of which are kept in fixed positions, the third one being adjusted when the hand knobs are attached or removed. When reorienting the microscope, the hand knobs on each side of the instrument are gripped as shown in Fig. 2. Provided that the tension of the various joints of the instrument is properly adjusted, this grip makes it very easy to place the microscope in

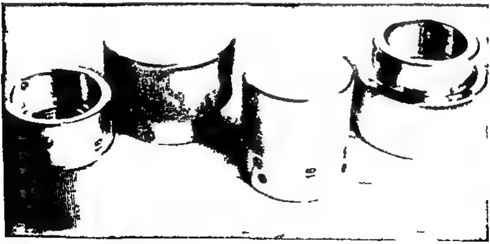

Fig. 1. The hand knobs unmounted.

FIG. 8 The hand knobs mounted on the microscope and the grip for reorienting the microscope

an exact position. Because of their size the hand knobs are easy to find without removing the eyes from the eyepieces. At the same time they keep the hands of the surgeon at a safe distance from the body of the microscope. For approximately two years hand knobs of this type have been in use at our clinic.

STAPEDEKTOMIE MIT INTERPOSITION

Venentransplantation und Reposition des modifizierten Steigbügels in 204 Otosklerosefällen

L. Rüedi und Ch. Suter
Zürich, Schweiz

Aus der Otorhinolaryngologischen Universitäts-Klinik (Direktor: Prof. Dr. L. Rüedi), Zürich

Seit Juni 1959 ist die Stapedektomie mit Interposition eines Venentransplantates und Reposition des modifizierten Steigbügels an der Zürcher Klinik die Methode der Wahl in der Behandlung der otosklerotischen Schwerhörigkeit. Bis Ende April 1961 sind vom gleichen Operateur 204 Fälle auf die genannte Weise operiert worden. In 2 weiteren Fällen war die Stapedektomie wegen zu grossen technischen Schwierigkeiten nicht ausführbar.

A. Selektion der Fälle

Von den 204 Fällen konnten 193 statistisch ausgewertet werden.

Die 11 nicht verwerteten Fälle werden aus folgenden Gründen ausgeschieden: Status nach Mastoidektomie und Residuen (1 Fall). Stapedektomie-Reoperation mit Einsetzen einer Akrylithprothese (1 Fall). Sogenannte Versuchsfälle, in denen die präoperative Luftleitungsschwelle nicht oder erst bei 70 db (500 Hz) und bei 90 db (1000 Hz) bestimmbar und die Knochenleitungsschwelle nur bei 500 und 1000 Hz messbar war (9 Fälle).

Trotz der schlechten Ausgangslage ist in der Gruppe der Versuchsfälle in 6 von 9 Ohren ein Hörgewinn erzielt worden, der von den Kranken sehr hoch eingeschätzt wird, selbst wenn dadurch nur eine Verbesserung des Hörens mit einem Hörapparat zustande kommt.

Auswahl der Operationsseite und Verhältnisse auf der Gegenseite

	Fälle
Schlechteres Ohr zuerst operiert	111
Besseres Ohr zuerst operiert	13
Hörschwellen in beiden Ohren identisch	4
Beide Ohren operiert (9 Patienten)	18
Bogengangsfenestration contralateral	32
Malleopexie contralateral	1
Incudopexie contralateral	[illegible]
Mobilisation contralateral	5
Mobilisation homolateral	[illegible]
Mobilisation beiderseits	1
Mobilisation homolateral und Bogengang-fenestration contralateral	6
Mobilisation homolateral und Incudopexie contralateral	1
Einseitige Otosklerose, früher mobilisiert	1
Radikaloperation contralateral	1
Total	204

B. Auswertung des Materials

Die statistischen Berechnungen stützen sich auf die über Luft- und Knochenleitung gemessenen Reintonaudiogramme. Dabei wird der im Bereich der drei Sprachfrequenzen 500, 1000 und 2000 Hz sich ergebende Mittelwert verwendet. Die Teste werden durch Ohrenärzte in der schallisolierten Kammer mit dem geeichten Beotonaudiometer ausgeführt. Die Töne werden dem Ohr zur Vermeidung von adaptationsbedingten Fehlern intermittierend angeboten. Dabei wird als Hörschwelle die schwächste Intensität, welche beim Aufsteigen vom Nichthören zum Hören wahrgenommen wird, aufgezeichnet. In 16 Fällen muss ein ausserhalb der Klinik angefertigtes Audiogramm herangezogen werden, alle übrigen Audiogramme stammen aus unserer Klinik.

Es wird folgende Selektion der Audiogramme getroffen:

1. Das praeoperative Audiogramm.
2. Die postoperativen Audiogramme
   a) 1–4 Wochen post operationem
   b) 3 Monate post operationem
   c) 6 Monate post operationem
   d) 12 Monate post operationem

Da viele Patienten der Aufforderung zur Gehörskontrolle nicht sofort Folge leisten, werden die nach 3 oder 6 Monaten kontrollierten Fälle in eine Gruppe zusammengezogen. Falls sowohl nach 3 als auch nach 6 Monaten ein Audiogramm vorliegt, wird das letztere berechnet.

C. Klassifikation des Materials

I. Nach audiologischen Gesichtspunkten

Zur Klassifikation wird die neue Shambaugh-Formel verwendet, die auf dem Durchschnitt der praeoperativen Knochenleitungsschwellen der drei Sprachfrequenzen 500, 1000 und 2000 Hz beruht. Folgende 4 Gruppen werden unterschieden:

A — Fälle	Durchschnittliche Knochenleitungsschwelle	0–15 db
B — Fälle	Durchschnittliche Knochenleitungsschwelle	16–25 db
C — Fälle	Durchschnittliche Knochenleitungsschwelle	26–35 db
D — Fälle	Durchschnittliche Knochenleitungsschwelle	über 35 db

TABELLE 1

	♂	♀	Total	Praeop. air bone gap
A — Fälle	62	55	117 (60%)	45 db
B — Fälle	28	22	50 (26%)	42 db
C — Fälle	11	8	19 (10%)	39 db
D — Fälle	6	1	7 (4%)	37 db
Total	107	86	193 (100%)	

TABELLE 2

	OZ	OV	EZ	EV	Total
A — Fälle	56	14	11	36	117
B — Fälle	22	7	4	17	50
C — Fälle	12	2	3	2	19
D — Fälle	5	1	—	1	7
Total	95	24	18	56	193
	49 %	13 %	9 %	29 %	100 %

II. *Klassifikation anhand der pathologisch-anatomischen Veränderungen im Bereich des ovalen Fensters und der Steigbügelfussplatte*

Die Fensternische ist offen oder eingeengt, die Fussplatte ist zart oder verdickt. So entstehen vier Kombinationsmöglichkeiten:

OZ Offene Nische, zarte Fussplatte
OV Offene Nische, verdickte Fussplatte
EZ Eingeengte Nische, zarte Fussplatte
EV Eingeengte Nische, verdickte Fussplatte

In der Tabelle 2 werden 193 Fälle in bezug auf die audiologische Einteilung (Shambaugh) und in bezug auf die pathologisch-anatomischen Veränderungen einander gegenübergestellt. Danach besteht zwischen dem Verlauf der durchschnittlichen praeoperativen Knochenleitungsschwelle und den otosklerotischen Veränderungen im Bereich des ovalen Fensters kein regelmässiges Verhältnis.

III. *Klassifikation auf Grund der durch die Operation erzielten audiometrischen Resultate*

Hörgewinn oder Hörverlust werden anhand der praeoperativen und der postoperativen Luftleitungsaudiogramme berechnet, indem der im Bereich der drei Sprachfrequenzen 500, 1000 und 2000 Hz sich ergebende Mittelwert angewandt wird.

TABELLE 3

	Post op		Nach 6 Mt		Nach 12 Mt	
Gruppe	Fälle	db	Fälle	db	Fälle	db
A	117	29	73	29	40	30
B	49	31	28	33	15	37
C	18	28	13	30	8	30
D	7	[illegible]	5	3	1	30
Total	191	30	119	32	64	32

Tabelle 4

	db	A	B	C	D	Zahl	%
+	51–60	2	—	—	1	3	1 6
	41–50	13	7	3	[illegible]	25	13 0
	31–40	41	19	3	—	63	32 6
	21–30	41	15	[illegible]	[illegible]	66	34 2
	11–20	[illegible]	8	4	—	24	12 5
	0–10	7	—	1	—	8	4 1
–	0–10	1	—	—	—	1	0 5
	11–20	—	—	—	1	1	0 5
	Taubheit	—	1	1	—	2	1 0
	Total	117	50	19	7	193	100 0

Die Tabelle 3 gibt Auskunft über die durchschnittlichen Hörgewinne welche unmittelbar post operationem 6 Monate post operationem und 12 Monate post operationem in den vier Shambaugh Gruppen erzielt worden sind

In 191 von 193 statistisch verwerteten Fällen (2 Ertaubungen) beträgt der durchschnittliche postoperative Hörgewinn 30 db Nach 6 Monaten beträgt der Hörgewinn in 119 Fällen 32 db und nach 12 Monaten in 64 Fällen ebenfalls 32 db Der praeoperative Verlauf der Knochenleitungskurve hat keinen Einfluss auf den operativen Hörgewinn

In den Tabellen 4 5 und 6 kommt das individuelle Ausmass des Hörgewinnes bzw des Hörverlustes in bezug auf die vier Shambaugh Gruppen unmittelbar post operationem 6 Monate und 12 Monate später zur Darstellung

Nachdem sich in diesen 3 Tabellen keine Beziehung zwischen dem Verlauf der praeoperativen Knochenleitungskurve und dem Hörgewinn bzw Hörverlust feststellen lässt werden die Fälle der A B C und D Gruppen zusam

Tabelle 5 *6 Monate post operationem*

db	A	B	C	D	Zahl	%
51–60	—	1	—	[illegible]	3	2 5
41–50	11	5	3	1	20	16 5
31–40	29	11	3	—	43	3[illegible] 5
21–30	17	8	4	1	30	24 8
11–20	10	2	[illegible]	—	14	11 6
0–10	3	1	1	1	6	5 0
0–10	3		—	—	3	2 5
11		—	—	—		—
Taubheit	—	1	1	—	2	1 6
Total	[illegible]3	29	14		121	100 0

TABELLE 6 *12 Monate post operationem*

	db	A	B	C	D	Zahl	%
+	51–60	2	2	—	—	4	6,1
	41–50	[illegible]	3	2	—	11	16,7
	31–40	10	8	2	—	30	30,3
	21–30	16	—	1	1	18	27,3
	11–20	3	2	3	—	8	12,1
	0–10	2	—	—	—	2	3,0
−	0–10	1	—	—	—	1	1,5
	11–20	—	—	—	—	—	—
	Taubheit	—	1	1	—	2	3,0
	Total	40	16	[illegible]	1	66	100,0

mengefasst. Die Verteilung der Hörgewinne post operationem, nach 3 bis 6 und nach 12 Monaten zeigt das Bild in der Tabelle 7.

Einen Hörgewinn von 11 und mehr Dezibel erreichen (in Klammern Zahlen von Myers, Schlosser und Winchester):

Post operationem 181 (222) von 193 (250) Fällen = 93,9% (88,8%)
Nach 6 Monaten 110 (92) von 121 (108) Fällen = 90,9% (85,2%)
Nach 12 Monaten 61 (52) von 66 (62) Fällen = 92,[illegible]% (83,9%)

Hürzeler hat im Stapesmobilisationsmaterial der Zürcher Klinik in 77 von 126 Fällen, d. h. in 61%, einen postoperativen Hörgewinn von 11 und mehr Dezibel gefunden.

TABELLE 7

db	Post op. 193 Fälle		Nach 6 Mt. 121 Fälle		Nach 12 Mt. 66 Fälle	
	Fälle	%	Fälle	%	Fälle	%
51–60	3	1,6	3	2,5	4	6,1
41–50	25	13,0	20	16,5	11	16,[illegible]
31–40	[illegible]	3[illegible],6	43	35,5	20	30,3
21–30	66	34,2	30	24,8	[illegible]	27,3
11–20	24	12,5	14	11,6	8	12,1
0–10	8	4,1	6	5,0	[illegible]	3,0
0–10	1	0,5	3	2,5	1	1,5
11–20	1	0,5	—	—	—	—
Taubheit	[illegible]	1,0	2	1,6	2	3,0
Total	193	100,0%	121	100,0%	66	100,0%

Tabelle 8. Air-bone gap prae- und post operationem in 193 stapedektomierten Ohren

Gruppe	Prae operationem Fälle	db	Post operationem Fälle	db	Nach 3–6 Mt Fälle	db	Nach 12 Mt Fälle	db
A	117	45	117	14 (16)	73	13	40	13
B	50	42	49 +1 taub	13 (11)	28	12	15	12
C	19	39	18 +1 taub	13 (11)	13	12	8	18
D	7	37	7	12 (6)	5	15	1	9
Total	193	41	191 +2 taub	13 (11)	119	13	64	13

Vergleich der Hörgewinne von 11 und mehr Dezibel verschiedener Autoren

Portmann	94% (nach 3 und mehr Monaten)
Shea	91% (nach 12 Monaten)
Myers, Schlosser u. Winchester	88,8% (postoperativ)
Zürcher Klinik	93,9% (postoperativ)
Zürcher Klinik	92,5% (nach 12 Monaten)

Unter dem air-bone gap wird die Differenz zwischen der im gleichen Zeitpunkt gemessenen Luftleitungs- und Knochenleitungsschwelle verstanden. Der Rechnung liegt der im Bereich der drei Sprachfrequenzen 500, 1000 und 2000 Hz sich ergebende Mittelwert zu Grunde.

Da in anderen Statistiken z. T. stets die *praeoperative* Knochenleitungsschwelle als Basis zur Berechnung des air-bone gap verwendet wird, geben wir in der Tabelle 8 in Klammern den entsprechend berechneten air-bone gap an.

Der in 193 Fällen ermittelte durchschnittliche air-bone gap beträgt vor der Operation 41 db. Durch die Stapedektomie mit Interposition eines Venentransplantates und Reposition des modifizierten Steigbügels kann der durchschnittliche air-bone gap in 191 Fällen auf 13 Dezibel reduziert werden. Nach 3–6 Monaten beträgt der durchschnittliche air-bone gap ebenfalls 13 db und dieser Wert wird auch in 64 nach 12 Monaten kontrollierten Fällen beibehalten.

Wird der air-bone gap immer auf die praeoperative Knochenleitungsschwelle bezogen, so zeigt sich, dass dieser im Durchschnitt 2 db kleiner ist, d. h. 11 anstelle von 13 db in 191 postoperativ audiometrierten Fällen. Darnach liegt die Knochenleitungsschwelle prae operationem etwas tiefer als post operationem. Um zu prüfen, ob im Anschluss an die Stapedektomie eine Verbesserung der Knochenleitung eintritt, wie diese bei der Bogengangsfenestration von Davis und Walsh, sowie von Carhart und von Shambaugh gezeigt

wurde. Vergleichen wir die in 191 Fällen gemessene durchschnittliche präoperative Knochenleitungsschwelle mit der in denselben Fällen erhaltenen durchschnittlichen postoperativen Knochenleitungsschwelle und gelangen dabei zu folgenden Resultaten:

Durchschnittliche praeoperative Knochenleitungsschwelle	16.5 db
Durchschnittliche postoperative Knochenleitungsschwelle	15.2 db
Differenz	1.3 db

Die geringe, 1.3 Dezibel messende Verbesserung der postoperativen Knochenleitung ist statistisch nicht verwertbar. Rosen, Bergmann und Grossmann stellen fest, dass die Stapesmobilisation keine signifikante Verbesserung der Knochenleitungsschwelle bewirkt, und es scheint nun, dass auch die Stapedektomie auf die Innenohrfunktion in diesem Sinne keinen Einfluss ausübt.

In den Tabellen 9, 10, 11 wird die Verteilung der Fälle auf Gruppen mit einem air-bone gap von 0–10 db, 11–20 db, 21–30 db, 31–40 db, 41–50 db und 51–60 db gezeigt.

TABELLE 9. *Postoperativer air-bone gap*

db	A	B	C	D	Total	%
0–10	30	20	6	3	68	35.2
11–20	60	25	10	3	98	50.8
21–30	14	[illegible]	[illegible]	1	19	9.9
31–40	3	1	—	—	4	2.1
41–50	1	1	—		2	1.0
51–60		—		—	—	—
Taubheit	—	1	1	—	2	1.0
Total	11[illegible]	[illegible]	19	[illegible]	193	100.0

TABELLE 10. *Air-bone gap nach 6 Monaten*

db	A	B	C	D	Total	%
0–10	31	[illegible]	6	4	60	49.9
11–20	22	9	5	—	36	29.8
21–30	15	[illegible]	2		19	15.8
31–40	[illegible]					1.6
41–50		1		1	2	1.6
51–60						—
Taubheit		1	1		[illegible]	1.6
Total	3[illegible]	9[illegible]	14	5	121	100.0

TABELLE 11 *Air bone gap nach 12 Monaten*

db	A	B	C	D	Total	%
0–10	22	8	2	1	33	50.0
11–20	8	4	3	—	15	22.7
21–30	6	2	1	—	[illegible]	13.7
31–40	3	1	[illegible]	—	6	9.1
41–50	—	—	—	—	—	—
51–60	1	—	—	—	1	1.5
Taubheit	—	1	1	—	2	3.0
Total	[illegible]	16	9	1	66	100.0

Unter Schluss des air–bone gap verstehen wir eine Differenz von 0–10 db zwischen der Luft- und Knochenleitungsschwelle, welche anlässlich ein und derselben audiometrischen Untersuchung gemessen wird. Einen solchen Schluss des air–bone gap zeigen

Post operationem	*68 von 193 Fällen*	35.2%
Nach 3–6 Mt	60 von 121 Fällen	49.6%
Nach 12 Mt	33 von 66 Fällen	50.0%

Portmann gibt in 96 von 135 nach 3 und mehr Monaten kontrollierten Fällen, d. h. in 71% einen Schluss des air–bone gap an. Ewert und Shea zeigen in 94 von 100 nach 12 Monaten audiometrierten Fällen, d. h. in 94% einen Schluss des air–bone gap. Kos erzielt in 90 von 100 Stapedektomiefällen einen Schluss des air–bone gap. Schuknecht, McGee und Colman haben in 74.9% ihrer nach 4 Monaten kontrollierten Fälle einen air–bone gap von 0–10 db. Myers, Schlosser und Winchester haben in ihrem Material post operationem in 117 von 250 Fällen, d. h. in 46.8%, nach 6 Monaten in 54 von 108 Fällen, d. h. in 50% und *nach 12 Monaten in 31 von 62 Fällen, d. h. in 50%* einen Schluss des air–bone gap. Ewert und Shea weisen darauf hin, dass ihre sehr guten Zahlen auch von Portmann erreicht wurden. Tatsächlich erwähnt Portmann, dass in 128 von 135 Fällen, d. h. in 94% ein ausgezeichnetes *oder gutes Resultat erzielt wurde. Dabei weisen aber nur die weiter oben* erwähnten 96 Fälle, d. h. 71% einen air–bone gap von 0–10 db auf, weitere 32 Fälle, d. h. 23% zeigen einen air–bone gap von 11–30 db. Fassen wir die Fälle der Zürcher Klinik auf die gleiche Weise zusammen, so ergeben sich Ziffern in der Tabelle 12.

TABELLE 12 *Air bone gap (%)*

db	Post operationem	Nach 3–6 Monaten	Nach 12 Monaten
0–10	35.2	49.6	50.0
11–20	30.8	29.8	22.7
21–30	9.9	15.8	13.7
Total	75.9	95.2	86.4

TABELLE 13

Taubheit	Kein Hörgewinn		Hörverlust
	Post operationem	Nach 3–6 Mt	
2 von 204 Fällen	8 von 191 Fällen	4 von 119 Fällen	2 von 191 Fällen
0,98%	4,1%	3,3%	1,0%
	A 8 db →	A 12 db	
	A 8 db →	A 20 db	
	A 8 db →	A 2[illegible] db	
	A 6 db	A 6 db	
	A 10 db	A [illegible] db	
	A 5 db	A [illegible]	
	A [illegible] db	A [illegible]	
			A 8 db
B			
C			
	C 10 db →	C 30 db	
			D 12 db

Versagerfälle

Wenn post operationem eine Ertaubung eintritt, wenn keine mehr als 10 db betragende Hörverbesserung erzielt wird oder wenn die postoperative Luftleitungsschwelle unter der praeoperativen liegt, sprechen wir von Versagerfällen.

Die Tabelle 13 gibt die Versagerfälle wieder, die nach Shambaugh-System unterteilt werden.

In 2 von 204 Fällen, d. h. in 0,98% tritt post operationem eine Labyrinthitis mit konsekutiver Ertaubung ein. Dieser Labyrinthausfall ist in 1 Fall auf eine operative Schädigung der Labyrinthweichteile im Vestibulum zurückzuführen infolge von vergeblichen Extraktionsversuchen einer eingeklemmten Fussplatte. Im zweiten ertaubten Fall bleibt die Ursache der postoperativen Labyrinthitis unbekannt. Acht von 191 Fällen, d. h. 4,1% zeigen post operationem keinen verwertbaren Hörgewinn, aber in 4 dieser 8 Fälle verbessert sich im weiteren postoperativen Verlauf das Gehör doch um 12 bis 30 db. Zwei von 191 Fällen weisen post operationem eine um 8 bzw. 12 db schlechtere Luftleitungskurve auf als vor der Operation. Wahrscheinlich handelt es sich in diesen Fällen um einen Verschluss des runden Fensters.

Regression

Als regredient bezeichnen wir im Sinne von *Rosen* Fälle, in denen das Mittel der drei Sprachfrequenzen um 15 und mehr Dezibel schlechter geworden ist als die beste jemals nach der Operation gemessene Luftleitungsschwelle. Diese Abnahme muss im späteren postoperativen Verlauf erfolgen

TABELLE 14

Luftleitungsverlust	Knochenleitungsverlust	Kombiniert Luft-Knochenleitungsverlust
A OZ		
A EV		
A EV		
A EV		
	A EZ	
		A OZ
		A LZ
B EV		
C EZ		
D EV		
von 119 Fallen 5 8%	1 von 119 Fallen 0 8%	2 von 119 Fallen 1 6%

und es spielt keine Rolle ob die Luftleitungsschwelle noch uber der 30 Dezibellinie liegt bzw ob der air–bone gap noch immer geringe Werte aufweist

In der Tabelle 14 werden die regredienten Falle unter Berucksichtigung der pathologisch anatomischen Veranderungen und nach Shambaugh Gruppen klassifiziert wiedergegeben

Myers *et al* geben in ihrem ahnlichen Material in 5 7% der Falle Regression durch Schalleitungsverlust und in 2 8% durch Schallperzeptionsverlust an

In unserem Material sind 10 von 119 3 6 Monate kontrollierten Fallen d h 8 2% regredient In 7 der 10 Falle scheint ein Wiederverschluss des ovalen Fensters wahrscheinlich insbesondere da wir in 6 der 7 Falle eine eingeengte Fensternische bei der Operation vorfinden In 1 weiteren Fall verschlechtert sich postoperativ die Innenohrfunktion um durchschnittlich 15 db In 2 Fallen entwickelt sich sowohl ein Schallperzeptions als auch ein Schalleitungsverlust Die Regressionsziffer von 8 2% ist verglichen mit der von Hurzeler im Zurcher Stapesmobilisationsmaterial gefundenen Zahl von 64% als sehr gering zu betrachten

Fussplatte im Vestibulum

In 6 von 204 Fallen wird die Fussplatte ganz oder teilweise ins Vestibulum luxiert Ein Fall dieser Gruppe ertaubt wie schon ausgefuhrt worden ist in einem zweiten Fall geht der postoperative Horgewinn wieder zuruck und zwar entwickelt sich eine Schalleitungsschwerhorigkeit wahrend das Innenohr trotz der ins Vestibulum luxierten Fussplatte normal funktioniert In den 4 ubrigen Fallen scheint die ins Vestibulum verlagerte Fussplatte die Ohrfunktion nicht zu beeinflussen

4 ... t ... ryng

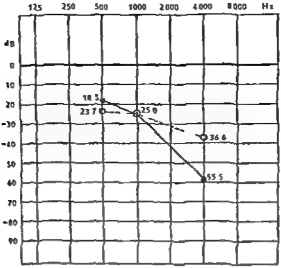

FIG. 1

Veränderung der Luftleitungsschwellen bei 500, 1000 und 4000 Hz 3–6 Monate nach der Operation

In der obenstehenden Fig. 1 kommt das durchschnittliche Verhalten der Luftleitungsschwellen bei 500, 1000 und 4000 Hz in 110 Fällen, und zwar in der ausgezogenen Linie post operationem und in der unterbrochenen Linie 3–6 Monate post operationem zur Darstellung. Wohl infolge einer Erholung des chirurgisch traumatisierten Innenohres steigt das Mittel der Hörschwelle bei 4000 Hz im Verlauf von 6 Monaten post operationem um 18,9 db an. Demgegenüber sinkt die mittlere Hörschwelle bei 500 Hz im Verlauf dieser Zeit um 5,2 db. Wahrscheinlich hängt diese leichte Verschlechterung des Gehörs für die tiefen Töne mit einer gewissen Versteifung des schalleitenden Apparates zusammen, welche durch Adhäsionen des Trommelfells und auch des Stapesvenenbereiches im Bezirk des ovalen Fensters bedingt ist. Der mittlere Schwellenwert bei 1000 Hz bleibt unverändert.

Über die Dauerresultate der zur Zeit sehr aussichtsreich erscheinenden Stapedektomie mit Veneninterposition und Reposition des modifizierten Stapes können erst Kontrolluntersuchungen eines grossen Materials in 5–6 Jahren Auskunft geben.

ZUSAMMENFASSUNG

An der Zürcher ORL-Klinik ist von Juni 1959 bis April 1961 in 204 Otosklerose-Fällen vom gleichen Operateur die Stapedektomie mit Interposition eines Venentransplantates und Reposition des modifizierten Steigbügels durchgeführt worden. In 191 von 193 statistisch verwertbaren Fällen beträgt der durchschnittliche postoperative Hörgewinn im Sprachfrequenzbereich 32 db. In den gleichen 191 Fällen beträgt post operationem der durchschnittliche air-bone gap im Sprachfrequenzbereich 13 db.

In 181 von 191 Fällen, d. h. in 94 % wird post operationem ein Hörgewinn von 11 und mehr Dezibel erzielt. Zwei von 204 Fällen, d. h. 1 % sind post operationem ertaubt. In 10 von 119 über 3–6 Monate kontrollierten Fällen, d. h. in 8,2 % geht der *postoperative Hörgewinn durch Wiederverschluss des ovalen Fensters oder durch* Abnahme der Innenohrfunktion wiederum zurück. Eine Beurteilung der Dauerresultate ist anhand der erst während 12 Monaten kontrollierten Fälle zur Zeit noch nicht möglich.

SUMMARY

204 cases of otosclerosis were operated on at the Zurich E.N.T. Clinic between June 1959 and April, 1961. Stapedectomy with interposition of a vein graft and reposition of the modified stapes was performed by the same surgeon in all patients. Of 193 cases suitable for statistical analysis 191 cases achieved an average gain in hearing of 32 dB in the speech frequencies. The average post operative air bone gap in the speech frequencies of the same 191 cases was 13 dB. 181 of the 191 cases (94 %) showed an improvement in hearing of 11 dB or more. Post operative loss of hearing occurred in 2 out of the 204 cases (1 %). Out of 119 cases followed up for 3–6 months 10 (8.2 %) suffered a gradual loss of their hearing gain through closure of the oval window or diminution of inner ear function. An assessment of the long term results is as yet not possible, as follow up at present does not exceed 12 months.

RÉSUMÉ

A la clinique d'oto-rhino-laryngologie de Zürich, le même opérateur a pratiqué une stapédectomie avec interposition d'un greffon veineux et réposition de l'étrier modifié dans 204 cas d'otosclérose, de juin 1959 à avril 1961. On trouva que le gain auditif post opératoire dans les fréquences de la conversation était de 32 décibels dans l'analyse des 191 cas sur 193, qui pouvaient être utilisés pour la statistique. Dans ces 191 cas l'« air bone gap » dans les fréquences de la conversation était de 13 décibels. Dans 181 des 191 cas, c'est à dire dans le 94 % des cas le gain auditif post opératoire fut d'au minimum 11 décibels. Deux des 204 cas, c'est à dire le 1 % environ, a présenté une surdité post opératoire totale. Dans 10 cas sur 119 qui ont été contrôlés de 3 à 6 mois plus tard (8,2 %) le gain auditif obtenu a disparu soit en raison d'une baisse de la fonction de l'oreille interne. Une observation des résultats à longue échéance ne peut être encore établie car un recul suffisant nous manque.

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ORL Klinik der Universität, Rämistrasse 100, Zürich

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QUELQUES RÉSULTATS DU TRAITEMENT DU CANCER DE LARYNX

M. Baradouline
Moscou, U.S.S.R.

Un travail collectif des collaborateurs de la section otolaryngologique de l'Institut d'oncologie de l'U.R.S.S. dirigée par Madame Maria Baradouline, docteur en médecine, Moscou, U.R.S.S.

La survie après le traitement des tumeurs du larynx dépend de la localisation et du stade de la tumeur, de la méthode du traitement.

L'analyse des malades avec une survie de plus de 5 ans traités au service ORL de l'institut d'oncologie de Hertzen nous permet de voir les résultats suivants.

Au 1er stade le traitement chirurgical et radiologique donnent une guérison stable dans 80 % des cas.

Au 2e stade la guérison est égale à 73 %.

Au 3e stade la cure combinée (Rx thérapie + laryngectomie) donne une guérison de 61,6 %.

Au 3e stade le traitement seulement radiologique donne une guérison de 35 %.

Comme on sait, l'étude des résultats de différentes méthodes du traitement du cancer de larynx présente un grand intérêt. Sept cent quarante et un malades ont été soumis à un stricte contrôle à l'Institut dès 1945. On a procédé à un traitement différent. Faisant le total des résultats du traitement on se sert de la classification adoptée en l'Union Soviétique. Cette classification est basée sur les particularités anatomo-biologiques et cliniques du cancer de larynx.

L'utilisation de la classification prend en considération la localisation primaire et le stade du développement de la tumeur. Grâce à cette classification l'application de différentes méthodes du traitement du cancer est devenue plus claire, plus argumentée. Au cours de 10 ans (1945–1955) il y avait sous le contrôle de l'Institut 157 malades traités par une méthode chirurgicale, 229 malades traités par une méthode combinée et 355 malades auxquels l'irradiation était appliquée. Dans le premier groupe il y avait 18 malades sur lesquels on avait effectué d'abord des résections partielles, mais qui ont subi plus tard laryngectomie à propos de la récidive du cancer.

Le total des malades était ainsi 741, dont les femmes composent seulement 10 %. Les malades à l'âge de 40 jusqu'à 60 ans comprennent 70 % du total des malades. Les malades qui n'ont pas encore 40 ans composent 17 %, ceux qui ont déjà atteint 60 et de plus 13 %.

La structure histologique de la tumeur de larynx est le cancer planocellulaire kératodes. On a enregistré 606 cas de ce type du cancer. Soixante deux malades avaient le cancer planocellulaire non kératodes, 52 malades avaient d'autres formes histologiques: le cancer à petites cellules, basal solide, cylindro-carcinome et d'autres.

LA MÉTHODE CHIRURGICALE

Une résection partielle du larynx à l'aide de la laryngofissure ou les opérations du type Hautant, Gluck, Portmann et Sendoulski ont été effectuées sur 55 malades qui avaient le cancer du premier et du deuxième stades.

Pendant 5 ans on observait 43 malades. Ces personnes étaient tout à fait bien portantes.

Cent dix huit malades qui avaient le cancer du larynx du troisième stade avaient subi la laryngectomie.

Dans le cas du cancer du vestibule du larynx les opérations s'élargissaient: il était nécessaire d'enlever aussi l'os hyoïde. Habituellement dans tous les cas on procédait à l'ablation du larynx avec tous ses muscles. Cent huit malades (c'est à dire 66,6%) se portaient bien pendant 5 ans. (Le total des malades était 157.)

LA MÉTHODE COMBINÉE

Cette méthode était appliquée aux malades qui avaient le cancer du troisième stade. Le processus se localisait le plus souvent dans le vestibule du larynx ou occupait presque toute sa moitié. Parfois la seconde partie du larynx a été atteinte par la tumeur.

Dans ces cas l'irradiation avant l'opération créait les conditions ablastiques pour une opération postérieure. En même temps on constatait la diminution de la tumeur. Le plus souvent on procédait à une irradiation par les rayons X. Les doses de l'irradiation changeaient de 4000 r jusqu'à 8000 r; d'ailleurs les grandes portions ont été appliquées là où la tumeur se contractait plus vite et où l'on mettait son espérance seulement en l'irradiation. Quatre ou six semaines après une laryngectomie complète ou élargie eut lieu.

En somme 220 malades ont été traités par cette méthode. Durant 5 ans 148 malades (64,6%) étaient bien portants. Il faut dire que les résultats dans le groupe de malades traités par la méthode combinée sont un peu plus pires que ceux dans le groupe de malades traités par la méthode chirurgicale. Ce fait s'explique par l'état de maladie plus grave des personnes traitées par la méthode combinée. Il n'y avait que très peu de malades avec le deuxième stade du cancer.

L'IRRADIATION

Trois cent cinquante cinq malades (principalement des hommes) à l'âge de 40-60 ans ont été traités par l'irradiation.

On a deux types de l'irradiation. Dans le premier type la dose totale 6000-9000 r. Cette dose est partagée en parties égales qu'on applique au malades durant 5 semaines. Deux cent six malades ont été traités d'après ce type là. Soixante douze malades (35%) sont vivants pendant 5 ans.

Une partie des malades ont subi la laryngectomie. Vingt et un malades sont vivants pendant 5 ans.

Le deuxième type est basé sur l'augmentation quotidienne des doses d'ir-

Pharyngeal paresthesia a feeling of having a lump in the throat transient difficulties in swallowing short periods of transient hoarseness and eye disturbances such as flicker scotoma occur more seldom

According to the literature the syndrome is most common between the ages of 50 and 60 years The disease develops slowly and is manifested intermittently

The syndrome may appear confusing with diverse symptomatic pictures from different cranial nerves With the anatomical conditions and the experience of recent years regarding disturbances of the cerebral circulation however it should be possible at least theoretically to explain the symptomatic picture A recapitulation of the part of the anatomy concerned and theories concerning the origin of the cervical syndrome are therefore given in the following

Anatomy

The central nuclei of the sympathetic nervous system are situated in the lateral horns of the spinal cord There they form a sympathetic nucleus which extends from C8–L3 From here the preganglionic sympathetic fibres pass through the anterior horn of the spinal cord together with the anterior spinal roots and then on to the sympathetic ganglions as the white rami communicantes There they are relayed to other postganglionic sympathetic neurones These then travel as the grey rami communicantes mainly to vessels and spinal nerves and follow these to the innervation areas In the cervical cord cranial to C8 sympathetic neurones are lacking in the anterior spinal roots Postganglionic neurones pass from the cervical sympathetic ganglia especially from the stellate ganglion to the vertebral artery and form a plexus around this vessel the vertebral plexus This accompanies the vessel cranially and ramifies with the cerebral vessels The vascular branches arising from the basilar artery probably contain sympathetic neurones from the vertebral plexi of both sides The inner ear is innervated vegetatively by the vertebral plexus which ramifies with the labyrinth artery *According to Lewis the sympathetic innervation of the* inner ear has no connection with the middle ear which is innervated vegetatively by the carotid plexus through the carotico tympanic nerve

The vertebral artery passes from the 6th cervical vertebra upwards through the transverse costal foramina It is usually of a different calibre on each side According to Stopford's investigation in 1915 on a large anatomical material the vertebral vessels were of the same size in only 8% while in 72% the calibre of one of the vessels was at least double and in certain cases as much as 20 times as large as that of the other side Constriction of the larger vertebral artery should in these cases affect the distribution area of the basilar branches

The inferior posterior cerebellar artery arises from the vertebral artery and supplies the lateral part of the medulla oblongata and the inferior side of the cerebellum (Fig 1) It has poorly developed collaterals and as is

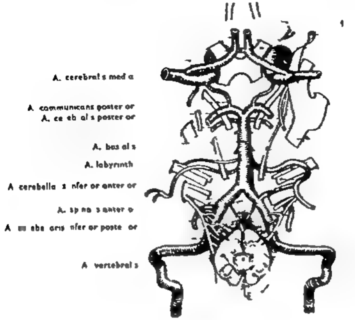


Fig. 1. Semi-schematic drawing of the vertebral artery and the basilar artery (after Krayenbühl & Yasargil 195)

known; its obliteration produces the Wallenberg syndrome. From the vertebral artery arise further the bulbar rami and the anterior and posterior spinal arteries, all of which supply the medulla oblongata.

The inferior anterior cerebellar artery usually arises from the basilar artery, but may sometimes arise from the vertebral artery.

The labyrinth artery may arise either from the inferior posterior cerebellar artery, the inferior anterior cerebellar artery or from the basilar artery (Krayenbühl & Yasargil 1957).

The vertebral artery supplies the greater part of the medulla oblongata, that part which lies below the medullary striae (Stopford 1915). Within this section lie the glossopharyngeal and vagal nuclei and parts of the trigeminal and vestibular nuclei.

In spondylosis deformans in the cervical spine, exostoses occur around the uncovertebral joints of the vertebral bodies. Exostoses arising laterally from the vertebral bodies can reach and displace the vertebral artery. Exostoses directed postero-laterally constrict the intervertebral foramina and may compress the spinal roots and produce root symptoms (see Fig. 2). With rotations in the cervical spine, especially with simultaneous backward bending and lateral rotation, the vertebral artery can become more or less compressed by the uncovertebral exostoses. Vertebral disc herniation, subluxations in the cervical spine and axial subluxations between the atlas and the axis may also, according to the literature, cause compressions of the vertebral artery on head rotation (Lindemann & Kuhlendahl 1953) (see Fig. 3).

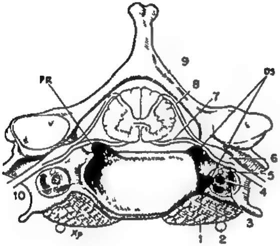


Fig 2

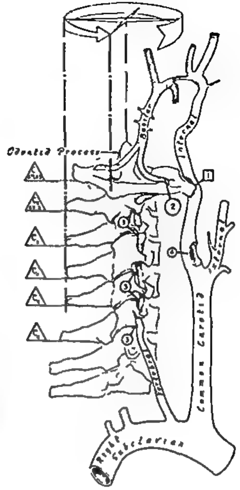


Fig 3

Fig 2 4, The vertebral artery OS, uncovertebral exostoses (after Neuwirth, 1951)
Fig 3 Schematic view of cervical spine and transcervical vessels, showing their relationships as the face is turned to the left (1) Compression of carotid artery by transverse process of atlas, as postulated by Boldrey (2) Distortion of the vertebral artery as it lies upon the atlas (3) Osteophytic compression of vertebral arteries (4) Frequent site of atherosclerotic plaques in the carotid artery (after Toole & Tucker, 1960)

Theories concerning the Origin of the Cervical Syndrome

The cause of the cervical syndrome has been attributed to ischemia in the distribution area of the vertebral artery, most frequently caused by pathological changes in the cervical spine As is evident from the anatomical review, such an ischemia may explain the pharyngeal, laryngeal and the vestibular symptoms

Toole & Tucker have recently shown on autopsy material how rotation and bending in the cervical spine could mechanically compress the vertebral artery, and also to a certain extent the internal carotid artery (see Fig 3) If there are osteochondrotic changes in the cervical spine, relatively moderate

head movements could affect the vertebral vessels and thus the cerebral circulation. Fig. 4*A*–C is taken from publications of Tissington Tatlow & Bammer (1957) and shows vertebral angiograms taken post mortem. In Fig. 4*A* uncovertebral exostoses may be seen displacing the right vertebral artery. If the head is rotated to the right, the right vertebral artery is compressed by these exostoses (Fig. 4*B*). The left vertebral artery is also constricted where it twists round the atlanto-occipital joint. On head rotation to the left the corresponding constriction of the right vertebral artery is seen at the level of the atlanto-occipital joint (Fig. 4*C*).

Roentgenologically observable deformities in the cervical spine are almost a normal finding in older age groups. Susse states that roentgenological changes occur in patients under 40 years of age in 25 %, 40–50 years of age in 50 %, 50–60 years of age in 70 % and in patients over 60 years old in 95 %. Similar information is given by Schoen (1956).

The majority of the patients with the cervical syndrome are in the upper middle age groups. According to Saker the cervical syndrome occurs in about 30 % of cases with roentgenologically demonstrated changes in the cervical spine.

It may thus be concluded that there are probably further causal factors for the development of the cervical syndrome. Blood vessel changes have been suggested as aetiological factors, especially arteriosclerosis. It is evident from anatomical considerations that the vascular pattern can itself vary considerably. There is reason to suppose that a cervical syndrome is developed only if the vascular pattern is such that a unilateral constriction of the vertebral artery cannot be compensated by collateral function of the contralateral vertebral artery or from the basilar artery through the circle of Willis. The extremely varying vascular pattern within the vertebro-basilar region also explains why certain patients survive even bilateral ligature of the vertebral artery, while others die after ligature of one vertebral artery, or, as has been reported, after vertebral angiography (Sugar & Bucy 1954).

More severe arteriosclerotic changes in the vertebral and basilar arteries may give symptoms which are clinically designated "basilar insufficiency" (Meyer, Sheehan & Bauer 1960). Extreme degrees of head rotation, which affect the vertebral artery and further impair the cerebral circulation, could in such cases constitute a direct threat to life. In, for example, endoscopy under anaesthesia, patients are often subjected to extreme degrees of head rotation, which in cases with vertebral insufficiency could be disastrous (Reddy 1961).

Barré and Lieou maintained the origin of the symptom complex to be a sympathetic irritation in the vertebral plexus caused by uncovertebral exostoses. Bärtschi-Rochaix, who named the syndrome "migraine cervicale", pointed out that the vertebral plexus and the vertebral artery constituted a functional unit. According to this hypothesis, changes in the cervical spine both mechanically compress the vertebral artery and also, by sympathetic irritation, produce vascular contraction with subsequent ischemia in the

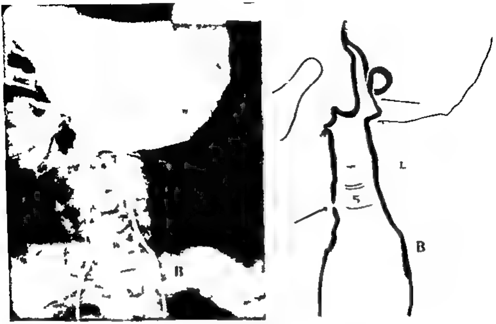
Fig. 43. After Tissington Tatlow & Bammer 1957. Bilateral angiogram of the vertebral arteries (antero-posterior). Free passage in both the vertebral arteries but uncovertebral exostoses at C5–C6 dislocate the right vertebral artery somewhat. See arrow.

distribution area of the vertebral artery. The extent to which the sympathetic system contributes to the syndrome is still unclear. Most authors appear, however, to share the view of Barré and Liéou and Bärtschi-Rochaix that a sympathetically provoked vascular contraction in the vertebral artery and its branches contributes to the ischemia in the vertebral distribution area. The hypothesis appears probable, but up to the present time has not been proved experimentally. The vascular spasms sometimes observed in vertebral angiographies and also the clinical course in many cases support the hypothesis, however.

The cause of the typical neck headache with temporofrontal radiation in the cervical syndrome is not clear. Sir Russell Brain points out that headache is not a common symptom in cervical spondylosis. It has been assumed that this is a question of "referred pain", possibly arising from the vertebral artery (Sir Russell Brain 1961).

Most authors mention the difficulty of diagnosing the symptoms in the cervical syndrome objectively. The diagnosis has had to be made almost entirely on the case history. Pfältz & Richter, however, objectively demonstrated nystagmus in the cervical syndrome in 1958 by means of a photoelectric recording technique.

The aim of the investigation reported in the following was to study the vestibular findings in the cervical syndrome. In the clinical otoneurological



F o 4B ■ hea l rotation to the right the right vertebral artery is compresse l by exo toses at C5–C6 The left ve tebral a tery i al o constr cte l at the level of the atlanto occ p tal jo nt See arrows

I 4C On hea l rotat on to tl e left the ri l t vertebral artery i con t cte l at the l vel f the atla to-occ pital joint See arrow

investigation the objective results given by electronystagmography should provide increased possibilities of both qualitative and quantitative nystagmic analyses and comparisons.

The suggestion for the investigation was given to me by Professor Sjöberg who by his studies of spinobulbar poliomyelitis has also taken interest in vestibular symptoms in spondylosis deformans (Sjöberg 1956).

INVESTIGATIONS

Method

All patients underwent a general otoneurological examination including an audiogram. The occurrence of nystagmus was also checked by the use of Frenzel's spectacles. Electronystagmography (ENG) with calorization was performed on all patients. This nystagmography was carried out using the technique and apparatus described by Aschan (1955) and Aschan *et al.* (1956). The method permits recording behind closed eye lids and the inhibition of nystagmus by visual influences is avoided.

The head position, head movements and neck rotation are three factors which may provoke nystagmus. In order to analyze these factors positional tests were performed according to the following scheme:

1. Supine position.

2. Head rotation to the right and left lateral positions of the head. The patient remains lying on his back. The head is rotated with passive movements to the extreme lateral positions, *thus involving rotation of the cervical spine.*

3. Lateral positions, right and left respectively. The patient lies with the head and the whole body in the lateral position in such a way that the head is not rotated or bent in relation to the body. *There is no rotation of the cervical spine.* An orthopedic supporting collar (Fig. 10) may be used with advantage to prevent neck rotation.

4. Sitting position. *No rotation or bending of the neck.* An orthopedic collar may be used for fixation.

5. Sitting position with *passive backward bending of the head and successive extreme head rotation to the right and left sides.*

6. Hanging position. The patient lies in the supine position and *with a passive movement the head is hung backwards* over the edge of the examination table, and then, still in the hanging position, *the head is rotated* passively to the right and left successively.

In the nystagmograms shown in Figs. 5, 7, 8 and 9, positions 2 and 3 have been combined under a common notation.

All of the positional tests described above were carried out *both very slowly* to avoid any provocation of movement induced nystagmus *and also with rapid changes of position* to reveal the occurrence of any such nystagmus.

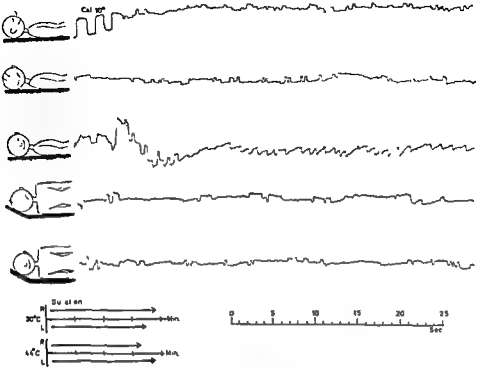


Fig. 5 On head rotation to the left left beating nystagmus

Fig. [illegible]

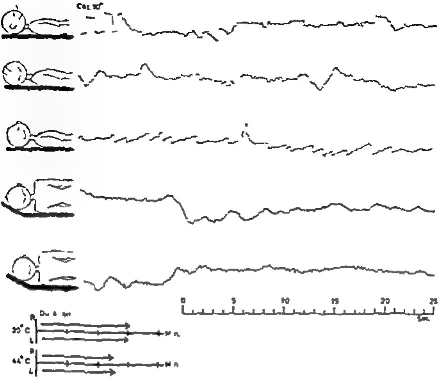


FIG. 7. On head rotation to the left, left beating nystagmus

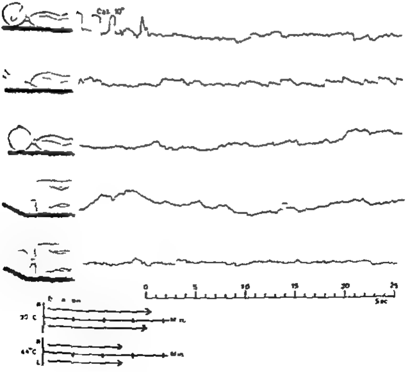


FIG. 8. [illegible] rotation to the right, right beating nystagmus

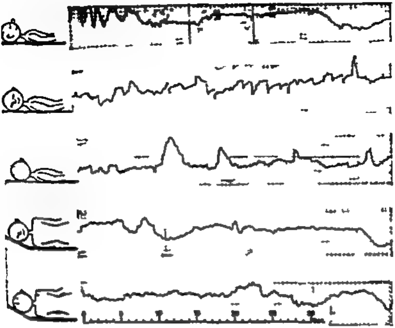


Fig. 9. On head rotation to the right left beating nystagmus.

In these cases where nystagmus was observed barbituric acid blood tests were taken to demonstrate any such possible source of error.

An X-ray examination of the cervical spine was also performed on all patients.

Fig. 10. Orthopedic fixation collar.

Material

The material comprised 100 cases: 51 women and 49 men. Of these 90 had been patients at the Orthopedic Clinic for the investigation of brachialgia and they were kindly made available by Professor Carl Hirsch, head of the Orthopedic Clinic. The majority of the patients had roentgenologically observable deformity changes in the cervical spine. It was supposed likely that these selected orthopedic patients with deformity changes in the cervical spine might also exhibit the cervical syndrome. The other 10 cases had originally attended the Ear Clinic with symptoms which indicated the cervical syndrome. Most of the patients were in the upper middle age group.

RESULTS

Just over a quarter—28 cases (groups I–IV)—of the patients investigated had symptoms resembling the cervical syndrome. Common symptoms were neck headaches radiating temporally towards the forehead or penetrating behind the eyes, and there were also deformity changes in the cervical spine. The patients have been classified in six different groups with regard to the presence of the cervical syndrome and the otoneurological findings.

The investigation results were classified according to the following table.

I	Cervical syndrome, cervico-vascularly provoked nystagmus	8
II	Cervical syndrome, nystagmus of other types	10
III	Cervical syndrome, subjective giddiness but normal vestibular status	5
IV	Cervical syndrome but no subjective or objective vestibular symptoms	5
V	Pathological vestibular status without signs of cervical syndrome	9
VI	Others	63
	Total	100

All cases in group I showed a positional nystagmus which was with great probability provoked cervico-vascularly. Figs. 5, 7, 8 and 9 show such nystagmograms. This positional nystagmus occurred only after head rotation to one side or the other (positional tests 2 and 3). It did not occur in the lateral position without neck rotation (positional test 4), in spite of the fact that the head and labyrinths assumed the same positions as in positional test 2. The vestibular effect must have been thus caused by the neck torsion. The nystagmus was of varying intensity, as a rule weak but nevertheless distinct. The intensity varied from 1.5°/sec. to 7°/sec. Usually the cervico-vascularly provoked nystagmus commenced after a latent period of 15–30 sec., and was in 7 cases of a transient type and in 1 case of a tonic type.

In group II both spontaneous and positional nystagmus occurred, both in positions with and without neck rotation. Such nystagmus cannot be ascribed with certainty to cervico-vascular provocation, but on the other hand the type of nystagmus does not contradict such a possible origin.

In group III the patients exhibited the cervical syndrome with giddiness but in spite of the nystagmography no nystagmus could be demonstrated

In group IV the symptoms were as in the cervical syndrome but there was subjectively no giddiness and no demonstrable nystagmus

Group V comprises [illegible] cases *with nystagmus but no symptoms indicating* the cervical syndrome These were cases for example with post concussive troubles the effects of barbituric acid or Menière s disease Also in this group there were patients with cervical spondylosis

The 63 cases in Group VI had either vestibular symptoms or symptoms indicating the cervical syndrome Deformity changes in the cervical spine also occurred to a very great extent among these cases

Patients with the cervical syndrome often had tinnitus and some observed that the singing in their ears had become more pronounced or had changed in character on head rotation On the other hand the audiogram showed nothing abnormal in these cases Most of the patients included in the investigation were of upper middle age and a moderate degree of presbyacusis was a common audiometric finding

Throat symptoms—a feeling of having a lump in the throat and difficulty in swallowing—occurred in a few cases

In the following some cases of cervical syndrome in which nystagmus was considered to be provoked cervico vascularly (group I) are reported

Case Histories

Case 2062/60

A 61 year old railwayman who had been previously healthy Had never had otitis but during recent years had been troubled by persistent headaches in the back of the head especially on the left side The pain radiated temporally towards the forehead and was sometimes felt as a pressing ache behind the left ear During the last few years the patient had also had short recurring attacks of rotatory giddiness particularly on head rotation Also tinnitus in the left ear

Normal tympanic membranes normal hearing X ray of skull ears and pori nothing abnormal found

Nystagmogram (*Fig* 5) On head rotation to the left and also in the sitting position with backward bending of the head and head rotation to the left the patient had a left beating nystagmus In the other positions no nystagmus

Caloric reactions Slight directional preponderance to the left

Case history and nystagmogram indicated the cervical syndrome When the case history was investigated further the patient revealed that he had injured his cervical spine during military service in 1940 Roentgen examination of the cervical spine showed gibbus formation at the level of C3 C4 after an old spinal fracture and also considerable deformity and secondary spondylosis with disc degeneration (see Fig 6)

Case 1697/60

A 48 year old woman previously healthy who for about 10 years had had pains in the neck radiating out to the arms especially the left arm and also

in the chest. Also pains in the back of the head radiating temporally towards the forehead and inwards behind the eyes. The pains were most pronounced on the left side.

For approximately a similar length of time she had had intermittent attacks of rotatory giddiness. The sensation of giddiness was most pronounced on backward bending.

Normal drum membranes. Audiogram showed nothing abnormal. General nervous state normal.

Nystagmogram (Fig. 7). There was a nystagmus beating to the left on head rotation to the left and also in the sitting position with backward bending and head rotation to the left. No nystagmus observed in the other positions. Caloric reaction normal.

X-ray cervical spine. Deformity changes at the level of C6–C7.

Left-sided vertebral angiography. Lateral displacement of the vertebral artery at the level of C6–C7. During the vertebral angiography the patient had a spasm in the vertebral artery. At the same time she had a severe attack of giddiness with nausea, which persisted for a few days. According to the patient, the giddiness was of the same character as her previous attacks but now lasted much longer.

Case 906/60

A 54-year-old man, who had been troubled for six months by right-sided brachialgia and also neck headache with temporo-frontal radiation on the right side.

For an approximately similar length of time he had had marked rotatory giddiness, particularly on head rotation. Otherwise in good health.

Tympanic membranes normal. Audiogram findings normal.

X-ray cervical spine. Deformity changes, compressed disc C6–C7.

Cervical myelography. Contrast defect at the level of disc C6–C7. Suspected disc herniation.

Nystagmogram (Fig. 8). On head rotation to the right, and also in the sitting position with backward bending and head rotation to the right, the patient had a right-beating nystagmus. No nystagmus in the other positions. Caloric reaction normal. See Fig. 8.

Case 1965/60

A 6? year old man, who during the last ten years had attended several clinics and doctors for diverse symptomatic pictures—chiefly headaches and giddiness. Since little or no objective support was found for the patient's symptoms, these were interpreted as mainly functional and he was diagnosed as a presenile hypochondriac.

During further otoneurological examinations the patient described the headaches as a feeling of pressure localized to the back of the head and a dull pain radiating temporally towards the forehead on both sides. He described

the giddiness as a constant feeling of uncertainty with periodic attacks of rotatory giddiness especially on head rotation No tinnitus

The patient stated spontaneously that he had periods of a sensation of a lump in the throat and transitory difficulty in swallowing His manner and general behaviour gave the impression of pre senile hypochondriasis The description of the symptoms however, indicated the cervical syndrome Roentgen examination of the cervical spine showed advanced osteochondrosis with disc degeneration Ear nose and throat nothing abnormal found Audiogram presbyacusis General nervous state nothing especially pathological found Nystagmogram showed a left beating nystagmus in all positions no definite positional influence

Hydergin tablets were given as an experiment At a re examination some months later the sensation of giddiness was better

Nystagmogram (Fig 9) This time the nystagmogram showed a transitory nystagmus beating to the left which occurred only on head rotation to the right Caloric reaction normal

DISCUSSION

In 7 of the 8 cases with cervically provoked nystagmus the nystagmus was of a transitory type and the nystagmus beat in the same direction as the head rotation In 1 case the nystagmus beat towards the opposite direction from the head rotation No direction changing nystagmus occurred, nor one beating vertically On *head rotation to one side the vertebral artery on the* other side is usually compressed The results of the investigation thus support the view that the nystagmus arose from the ischemic vestibular nuclei and from the ischemic labyrinth According to Toole & Tucker however the ipsilateral vertebral artery may also be compressed at times on head rotation (see also Fig 3*B*) Moreover the collateral possibilities of the vertebral vessels may be completely different No definite conclusions regarding the nystagmic direction in relation to the affected vestibular centres can therefore be drawn

In all cases the cervico vascularly provoked nystagmus was of low intensity but very distinct on the nystagmogram On the other hand it was difficult to observe with Frenzel s spectacles and in some cases was not seen at all This probably explains why nystagmus was so seldom observed previously in these cases and at the same time emphasizes the value of objective nystagmography in clinical otoneurological work Patients who have had nystagmus for a long time learn to practically overcome it by fixation As a rule the cervico vascularly provoked nystagmus occurred after a latent period of 15 30 sec which may perhaps be explained by the interval between the compression of the vertebral artery and the occurrence of ischemia in the vestibular organs There is also a latent period however with so called benign paroxysmal positional nystagmus

The caloric reaction was normal in these cases with a cervico vascularly

provoked nystagmus except in 1 case where there was a suggestion of a directional preponderance. This agrees well theoretically with the concept put forward here regarding the occurrence of vestibular irritations. A mild intermittent ischemia in the vestibular nuclei would not necessarily give any difference in tone. Consequently a normal calorigram may be expected. It is probable that a more pronounced ischemia in the vestibular nuclei and the labyrinth possibly caused by a prolonged sympathetically provoked contraction in the vertebral vessels gives a greater vestibular effect. This should then result in a difference in vestibular tone with directional preponderance and possibly spontaneous nystagmus. Such cases could conceivably be assigned to the second group in the classification. The varying types of nystagmus in the cervical syndrome may then be regarded as an expression of the varying degrees of ischemia in the vestibular centres. Compare case 1968/60 described above.

The positional nystagmus in group I was of a transitory type with the exception of 1 case. It is suggestive in this respect of positional nystagmus of benign paroxysmal type, which has been regarded inter alia as otolith provoked (Dix & Hallpike 1952). Other similarities to this type of nystagmus are the occurrence of an interval before its commencement and a normal calorigram. Such a nystagmus is provoked in the critical positions, however not always in connection with head rotation. Stahle's investigations in 1956 of paroxysmal transitory nystagmus with the same ENG method as has been used here showed that this nystagmus was of a considerably greater intensity, up to 55°/sec, and that the nystagmus sometimes changed the beat direction even when the patient retained his position. The nystagmus in group I was markedly weak with nystagmic intensities of 1–5.7°/sec. No change in direction of the nystagmus was recorded. The origin of transitory paroxysmal nystagmus is not clear; the actual movement in the changing of position may be the provoking factor (Aschan *et al.* 1957). The positional tests in this investigation were performed both slowly to avoid a movement-induced nystagmus and also rapidly. No change in the nystagmic intensity was observed in this way. This supports the view that the nystagmus recorded was not induced by movement but may be interpreted as being cervico-vascularly provoked.

In order to distinguish with more certainty cervically provoked nystagmus from other forms of positional nystagmus, Cope & Ryan have suggested a so-called collar test. The patient's neck and head is fixed in a plaster collar and the positional tests are carried out with and without this collar. In the present investigations I have used orthopedic fixation collars (Fig. 10) to prevent neck movement and tension in the neck muscles. Such collars are easy to apply and give good fixation. The positional nystagmus in group I occurred only on head rotation but not on using the fixation collar. Such a nystagmus probably cannot reasonably be regarded as otolith provoked. An otolith provoked positional nystagmus should also occur on positional changes without neck torsion.

A cervically provoked vestibular effect may also possibly arise from neck reflexes as described by Magnus and de Kleyn & Versteegh. It would probably be difficult to differentiate with certainty vestibular irritations caused by neck reflexes from those of a cervico-vascular origin as in the cervical syndrome. The rest of the clinical picture and the vertebral angiogram (if made) may provide guidance in the assessment of the vestibular findings.

With a vertebral angiogram compressions and anomalies in the vertebral and basilar arteries can be demonstrated with certainty. On the other hand the circulatory collateral function and the vascular pattern in the smaller vascular branches in the vertebral distribution area cannot as yet be satisfactorily studied. It is possible that with refined isotope measurements such local ischemia in the medulla oblongata and the cerebellum could be demonstrated objectively. To facilitate roentgen examinations with different head rotations in the vertebral angiogram, the insertion of catheters into the vertebral artery is required. The examination is therefore somewhat time-consuming and as reported in the literature not completely risk free (Sugar & Bucy 1954). It has to be decided, therefore, from case to case whether the clinical picture justifies such an examination.

Even the 63 cases in the investigation material who did not exhibit the cervical syndrome showed deformity changes in the cervical spine to a considerable extent. The reason why, in spite of this, they did not exhibit the cervical syndrome may possibly be that these patients constituted a normal material, i.e. their cerebro-vascular pattern was such that any constriction of the vertebral artery was compensated by good collateral function.

The cases reported here are predominantly orthopedic patients. Many of them had been severely handicapped by their brachialgia, while, on the other hand, they were less troubled by their giddiness. The cervical syndrome among the orthopedic patients had more or less the character of a secondary symptom to their often very severe radicular pains. The remaining cases with the cervical syndrome had originally attended or been referred to the Ear Clinic for the investigation of giddiness and headaches. Patients with the cervical syndrome do not constitute a solely otological clientele, but probably most often attend medical, neurological, neurosurgical and orthopedic clinics, especially if they have symptoms arising from the spinal nerves. Many patients also probably attend or are referred to a psychiatrist, since the symptoms are often wrongly interpreted as purely functional.

CONCLUSIONS

The cervical syndrome may be considered as an intermittent mild cerebral ischemia in the distribution area of the vertebral artery. The ischemia is caused by pathological changes in the cervical spine, particularly osteochondrosis, which on head rotation compresses the vertebral artery and also possibly causes sympathetically provoked contraction. *The chief factor in the*

occurrence of the syndrome is probably, however, a deficient collateral function in the vascular area of the vertebral and basilar arteries.

The subjective symptoms in the cervical syndrome are relatively typical but difficult to assess objectively. With nystagmography, however, there is greater possibility of objectively demonstrating the vestibular disturbances. *In some cases with the cervical syndrome there is a typical positional nystagmus which occurs only on head rotation and which can be presumed with great probability to be cervico-vascularly provoked.* In other cases of the cervical syndrome other types of nystagmus may occur, such as the spontaneous type. It is true that it cannot be certain that such a nystagmus is cervico-vascularly provoked, but, on the other hand, the nystagmic type does not contradict such an origin. In order to differentiate between cervically provoked nystagmus and that of other origins, complete positional tests must be carried out with and without neck rotations, such as have been described in this article. A cervically provoked nystagmus may, apart from the vascular origin, be due to neck reflexes. It is probably difficult to differentiate these two origins of the vestibular effect. It is possible that vertebral angiograms and the other clinical pictures may provide guidance in the assessment of the vestibular findings.

SUMMARY

The literature concerning the symptomatology of the cervical syndrome is first reviewed, and it is pointed out how anatomical conditions and pathophysiological experience may assist in explaining the occurrence of the cervical syndrome.

An otoneurological investigation of a series of 100 patients is described. Ninety of these patients had been investigated for brachialgia in an orthopedic clinic and were selected because it was considered likely that they would manifest the cervical syndrome also. Ten cases had originally attended the Ear Clinic with symptoms indicating the cervical syndrome. Most cases included in the material had had spondylosis deformans in the cervical spine. The cervical syndrome was present in 28%. Of these, 18 cases had nystagmus objectively demonstrable by means of nystagmography. There was one typical positional nystagmus which appeared only on neck rotation and which could be interpreted with great probability as cervico-vascularly provoked. The possibilities of differentiating positional nystagmus of a cervico-vascular origin from other forms of positional nystagmus are discussed. The author points out the importance of taking into consideration the position of the head in relation to the body in the investigation and assessment of positional nystagmus.

ZUSAMMENFASSUNG

Mit Angaben aus der Literatur als Ausgangspunkt wird die Symptomatologie des Cervicalsyndroms beschrieben. Es wird darauf hingewiesen, wie die anatomischen und pathophysiologischen Verhältnisse die Entstehung des Cervicalsyndroms erklären können.

Eine otoneurologische Untersuchung von 100 Patienten wird dargestellt Davon sind 90 Falle aus der Orthopadie, die wegen Brachialgien untersucht worden sind, und bei denen man deshalb annahm, dass sie die Voraussetzung haben, auch ein Cervicalsyndrom aufzuweisen Zehn Falle entstammen primar der Ohrenklinik, und kamen mit Symptomen, die fur Cervicalsyndrom sprachen Die Mehrzahl der Falle des Untersuchungsmaterials hat Spondylosis deformans in der Halswirbelsaule gehabt Das Cervicalsyndrom kam bei 28 % der Falle vor Davon hatten 18 Falle Nystagmus, der objektiv mit Nystagmographie nachgewiesen werden konnte Unter anderem kam ein typischer Lagenystagmus vor, der sich nur bei Kopfdrehung zeigte, und der mit grosser Wahrscheinlichkeit als cervical vaskular ausgelost aufgefasst werden kann Die Moglichkeiten, den Lagenystagmus von cervical vaskularer Genese von anderen Formen des Lagenystagmus zu unterscheiden wird diskutiert Der Verfasser weist auf die Wichtigkeit hin, die Lage des Kopfes im Verhaltnis zum Rumpf bei Untersuchung des Lagenystagmus zu beachten

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Ear, Nose and Throat Clinic, University Hospital, Uppsala

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INTRACOCHLEAR NEURINOMA

M. BALSLEV JORGENSEN
Copenhagen, Denmark

From the Department of Otology (Head: Prof. H. K. Kristensen, M.D.), Rigshospitalet (The University Hospital), Copenhagen

Intracochlear neurinoma was found in a patient in whom audiometric study, 6 months before death, had shown symmetrical hearing loss of the perceptive type. In the author's opinion the neurinoma cannot have been responsible for this hearing loss as the labyrinth showed only slight histological changes. Many other factors in the patient's history may have caused the hearing impairment. The tumour was found to have no relation to the vestibular branch of the acoustic nerve.

Intracochlear acoustic neurinomas are extremely rare and only a few have been reported. Marx (1926), Eggston & Wolff (1947) and Graf (1952) have reported one case each. The only patient with intracochlear neurinoma whose acoustic vestibular function had been studied is, to the author's knowledge, Wittmaack's (1929). In the course of systematic study of temporal bones in our laboratory we found a similar case in which clinical data were available.

CASE REPORT

The specimen of the left temporal bone was derived from a 58 year old woman who had been suffering, since the age of 28, from severe progressing rheumatoid arthritis which had proved refractory to any form of treatment. Twice she had been started on sanocrysin but it had to be withdrawn both times because of incipient intoxication in the form of stomatitis, tonsillitis and erythema. Later she had been treated, also unsuccessfully, with pituitary implantation, ACTH and cortisone. Gastric resection had been performed because of duodenal ulcer. During the latter years of life the patient's disease was complicated by chronic nephritis and gradually she developed oedema, anaemia and uraemia. Finally she succumbed showing signs of pneumonia. It must be mentioned also that during her prolonged disease she had a large consumption of salicylic acid.

During the last 10 years of life the patient showed increasing hearing impairment in both ears. During the last 3 or 4 years, however, the impairment did not progress further and the patient got on well with a hearing aid. The hearing impairment could not be put down to events in her general condition although she had noticed it after the second course of sanocrysin had to be interrupted. Occasionally she had slight tinnitus in both ears but never symptoms from the vestibular organs. On examination at the Ear Clinic 2½ years and 6 months before death the otoscopic

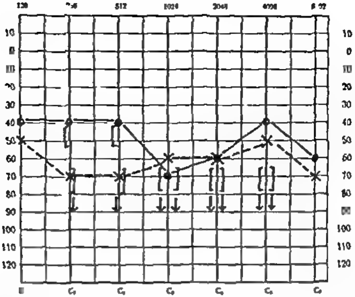

Fig. 1. O air conduction right. X, air conduction left. [bone conduction right.] bone conduction left. Audiograms 9.12.1954 and 18.12.1956 identical.

appearances were normal. As shown on Fig. 1, the audiograms were identical on both occasions. Regrettably, vestibular function tests were not carried out.

Autopsy was performed at the University Institute of Pathological Anatomy which reported the following diagnoses: rheumatoid arthritis, amyloidosis, sepsis, septic infarcts in the lower lobes of both lungs, bilateral fibrinopurulent pleurisy, acute pyelonephritis, necrotic papillitis of both kidneys, mild aortic and coronary atherosclerosis, mild cerebral oedema.

Special neuropathological examination including microscopic examination of tissue pieces from the left frontal lobe, hypothalamus, striate body, the motor region of the cortex, mesencephalon, pons, medulla oblongata, and cerebellum did not show any abnormalities, apart from mild oedema.

The left temporal bone was sent to our laboratory after fixation in "Kaformacete" (Wittmaack's solution). It was decalcified in equal parts of 8 % formic acid and 1 % sodium formiate and embedded in celloidin. Thereupon, it was sectioned horizontally, section thickness about 20 μ. Every 10th section was stained with heamatoxylin-eosin, and selected sections were treated by Kultschitsky's myelin sheath staining and PAS staining by the McManus method.

OBSERVATIONS

The tympanic membrane and middle ear were normal, without signs of chronic otitis. Auditory ossicles normally developed. Joints and ligaments without pathological changes. Labyrinthine capsule also normal, without signs of otosclerosis, especially around the base of the stapes.

Inner ear: semicircular canals and ampullae with cristae and cupulae without definite pathological changes. The macula sacculi and the macula utriculi were also normal. *Endolymphatic space of normal configuration*

without signs of collapse or distension. In the cochlea, in the basal turn of the scala tympani, there was about 2 mm from the round window, a typical neurinoma, about 3 × 2 × 1.5 mm occupying the entire lumen. The tumour had penetrated the wall towards the modiolus and was filling the greater part of Rosenthal's canal. The basilar membrane was resting directly on this tumour but nevertheless the sensory and sustentacular cells of Corti's organ showed no definitely pathological changes, being of an appearance like those in other parts of the cochlea, i.e. exhibiting some post mortem autolysis and partial collapse of Corti's canal. The tectorial membrane was normal. In the stria vascularis there was fairly pronounced autolysis but no definite signs of degeneration. Kultschitsky-stained preparations showed well preserved myelin sheaths to Corti's organ above the tumour. However, they were somewhat reduced in number. Where the tumour filled Rosenthal's canal a few degenerated ganglion cells were scattered in the tumour tissue. In all other sites the number and appearance of ganglion cells and myelin sheaths were normal. Reisner's membrane was in a normal position so there were no signs of altered pressure in the endolymphatic space. No changes of the modiolus apart from those described above. In the internal auditory canal the nerve was of normal appearance, and the myelin sheaths did not show signs of degeneration upon Kultschitsky staining. The ganglion cells in Scarpa's ganglion were normal in appearance and number. Nowhere penetration of the tumour to the internal auditory canal. The labyrinthine vessels stained specially by PAS staining showed no definite changes.

COMMENTS

Acoustic neurinomas are generally unilateral and are said to be extremely seldom of an intracochlear situation. As a rule, these tumours are assumed to restrict themselves to expansive growth in the internal auditory canal and only by erosion of the body wall have they ever been known to expose the membranous labyrinth. Bilateral acoustic neurinomas are generally links in multiple neurofibromatosis in which small neurofibromas are said to have been observed from time to time in an intralabyrinthine situation.

The *present study comprised only one of the patient's temporal bones* and although there is a theoretical possibility that she may have had a similar tumour in the contralateral temporal bone, this is not very likely since the autopsy did not reveal any signs of multiple neurofibromatosis.

Wittmaack's patient was 68 years of age and had been suffering for many years from Menière's disease with hearing loss in the right ear progressing to total deafness and repeated attacks of vertigo accompanied by nystagmus towards the affected side. Upon clinical examination one year before the patient died of cardiac infarction, Wittmaack found extinguished hearing in the right ear and slight hearing impairment, presumably senile, on the left. Examination of the vestibular apparatus showed no abnormalities, neither

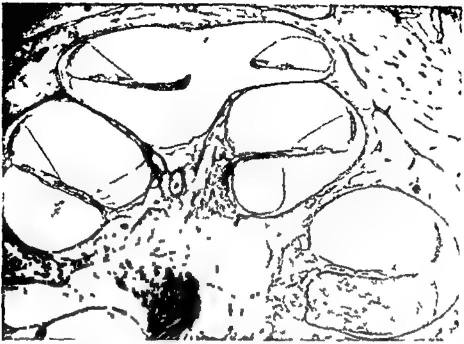

Fig. 2. Left cochlea with neurinoma in the basal turn. × 18. Haematoxylin-eosin.

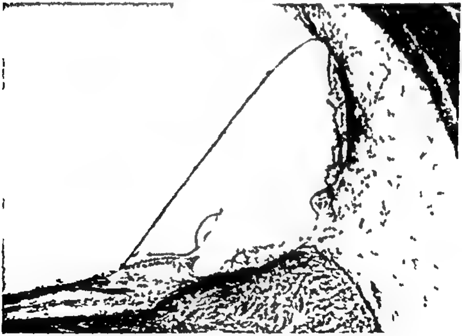

Fig. 3. Same as Fig. 2. × [illegible]. Kultschitsky staining.

upon rotatory nor caloric function tests. Subsequent histological study of the affected ear revealed an intracochlear neurinoma in the basal turn of the cochlea. Apart from posthydropic degeneration in the cochlear duct and a reduced number of ganglion cells and nerve fibres there were no definite pathological changes in the labyrinth. Wittmaack did not believe the neuri-

FIG. 4. Same as Fig. 2. The neurinoma does not penetrate to the internal auditory canal. 9[illegible] Kultschitsky staining.

noma could have caused the Ménière attacks, *inter alia* because the patient's disease was of such long duration, and in that event the neurinoma must have grown much larger.

In our case the same considerations apply. There was the same disproportion between the long duration of the hearing impairment and the small size of the tumour. Besides, the patient had been suffering from similar hearing impairment in the opposite ear. Although neurinomas have been known to grow slowly, the hearing would probably not have remained completely stationary for 2 years as shown by the audiograms.

As to the cause of the patient's hearing impairment we can only surmise. Several factors in her history are known to be able to cause hearing impairment of the perceptive type. This applies to chronic rheumatoid arthritis as well as to chronic nephritis. Moreover, the large quantities of salicylic acid which she had ingested in the course of time may have influenced her hearing.

In the discussion as to which part of the acoustic nerve neurinomas develop from, our finding militates against the assumption claimed by many authors that these tumours always arise from the vestibular branch.

ZUSAMMENFASSUNG

Es wird ein Fall von intracochlearen Neurinom von einem Patient mitgeteilt, wo bei der audiometrischen Untersuchung ½ Jahr vor dem Tode des Patienten

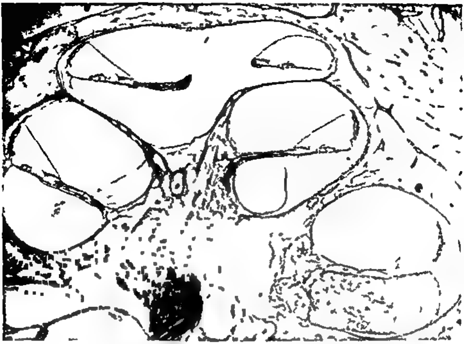

Fig. 2. Left cochlea with neurinoma in the basal turn. ×18. Haematoxylin-eosin.

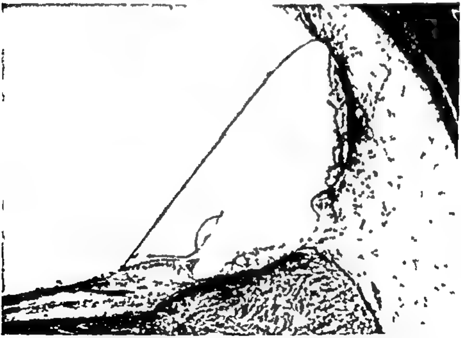

Fig. 3. Same as Fig. 2. ×90. Kultschitsky staining.

upon r[illegible] nor caloric function tests. Subsequent histological study of the affected [illegible] vealed an intracochlear neurinoma in the basal turn of the cochlea. A[illegible] from [illegible] posthydropic degeneration in the cochlear duct and a reduc[illegible] ber of ganglion cells and nerve fibres, there were no definite patholog[illegible] ges in the labyrinth. Wittmaack did not believe the neuri

THE CHOICE OF PROBE TUBE POSITION AND TEST FREQUENCY IN DETERMINING THE INTRA-AURAL REFLEXES

THORLEIF SOHOEL and GUNNAR ARNESEN
Oslo, Norway

From the Audiological Laboratory, the Ear, Nose and Throat Department (Head: Prof. Truls Leegaard), Ullevål Sykehus, Oslo

The present investigations have revealed changes in the sound pressure level in closed cavities with volume variations from 0.0 to 4.0 ccm, when under the influence of a tone of constant intensity and frequency. The changes are greatly dependent upon the frequency chosen. The method employed can be used for volume determination of small cavities, and may at the same time give enlightenment as to the most preferable position of the probe tube and the sealing material in the meatus during the electro-acoustical registration of the intra-aural muscle reflexes.

During the registration of the intra-aural muscle reflexes by means of electro-acoustical impedance measurements the results will to a certain degree depend on the position of the probe tube. It must fit closely to the walls of the meatus, and the opening must not be blocked by cerumen or debris. Experience shows further that the sound pressure level (SPL) in the meatus varies considerably, depending on the position of the probe tube and the sealing material in relation to the tympanic membrane.

This work is primarily intended to solve the following problem: Is the sound pressure level in reality dependent on the distance between the end of the probe tube and the tympanic membrane, and may therefore an optimal position of the tube be deduced from measurement of the sound pressure level in the meatus?

Apparatus

Fig. 1 shows in block scheme the electro-acoustical equipment employed for recording the intra-aural muscle reflexes. This apparatus was built for the purpose of qualitative demonstration of the muscle reflexes, not for the determination of the absolute impedance values (resistance and reactance). The probe is made of stainless steel with an inside diameter of 1 mm. Plastilina model wax is employed for sealing off the free space between the probe and the walls of the meatus. Test frequency: 500 cps.

By elicited muscle reflexes the sound pressure level of the test tone in the closed meatus cavity will rise, due to the increased middle ear impedance. The microphone voltage, which is read on the low frequency voltmeter, gives

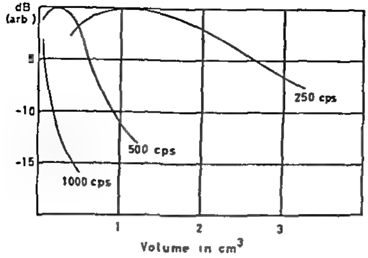

Fig. 3. SPL variations as a function of volume.

DISCUSSION AND CONCLUSIONS

The experiments are an attempt to find the signal frequency and the probe tube position which under the given circumstances result in smaller signal intensity variations caused by possible changes in the position of the tube openings. The mean volume of the meatus was in the case material presented found to be 1.11 ccm. By means of the electro-acoustical equipment employed in the present investigation the elicited intra-aural muscle reflexes are revealed through changes in the microphone signal amounting 0.5 db or more. The curves in Fig. 3 show, however, that signal variations of the same order may occur as a result of volume changes as small as 0.05 ccm with a chosen test frequency of 500 cps, if the probe tube is placed far out in the meatus, and of 0.2 ccm with a test frequency of 250 cps, if the tube is placed deep in the meatus. It is therefore quite possible that small volume variations in the meatus, due to head and jaw movements, may give signal changes of the

Table 1. *Volume of external auditory meatus*

Male		Female	
Right ccm	Left ccm	Right ccm	Left ccm
1.12	1.20	0.90	0.91
1.18	1.12	1.10	1.01
1.32	1.41	1.00	1.02
1.12	1.02	1.10	1.38
1.14	1.08	0.90	0.91
Average male 1.17 ccm		Average female 1.06 ccm	
Mean value for men and women 1.11 ccm			

same order as the alterations caused by intra aural muscle reflexes, if the test frequency and at the same time the position of probe tube are not chosen carefully. Further it appears from Fig. 3 that the smallest signal variation occurs by using a test frequency of 250 cps in closed volumes of 0.75 to 2 ccm. Hence it may be deduced that a low frequency test tone about 250 cps is preferable, and with an optimal position of the probe openings in the outer part of the meatus. A test frequency of 500 cps gives the smallest variations within a cavity volume of 0.1 to 0.3 ccm, which in turn implies that the optimal position of the probe and the sealing material under these conditions are close up to the tympanic membrane.

RÉSUMÉ

Les recherches actuelles ont révélé des variations du niveau de la pression du son dans des cavités closes avec des variations de volume de 0.0 jusqu'à 4.0 ccm, quand il y a influence d'un ton d'intensité et de fréquence constante. Les variations dépendant beaucoup de la fréquence choisie. La méthode employée peut être utilisée pour la détermination du volume des petites cavités, et peut en même temps donner des éclaircissements quant à la position la plus favorable du tube d'essai et du matériel d'obturation dans le méat pendant l'enregistrement électro acoustique des reflexes du muscle intraauriculaire.

ZUSAMMENFASSUNG

Vorliegende Untersuchungen haben eine Veränderung in dem Schalldruck in den geschlossenen Hohlräumen mit Volumvariationen von 0.0 bis 4.0 ccm nachgewiesen, wenn sie sich unter Einfluss eines Tones konstanter Intensität und Frequenz befinden. Die Veränderungen hängen in hohem Grade von der gewählten Frequenz ab. Die angewandte Methode kann für die Bestimmung kleiner Hohlräume angewandt werden und kann gleichzeitig Aufschluss über die beste Lage der Proberohren und des Schliessmateriales in dem Ohrgang (meatus) während der elektroakustischen Registrierung der Reflexen des Muskels des inneren Ohres geben.

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E. N. T. Dept., Ullevål Sykehus, Oslo

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THE GUSTO LACHRYMAL REFLEX

The Syndrome of Crocodile Tears

ALF AXELSSON and JAN ERIK LAAGE HELLMAN
Gothenburg Sweden

From the Department of Oto rhino laryngology Sahlgrenska Hospital Gothenburg

The gusto lachrymal reflex means lachrymation in connection with meals It usually appears after a facial paralysis on the affected side There are 67 cases mentioned in the literature Assuming that the syndrome is more common a follow up investigation has been made on 118 adults treated for facial palsy Among 92 examined 16 patients had noticed eye watering at meals Schirmer s test was used for measuring lachrymal secretion This method is not very reliable but the best of those available In spite of this the examination probably revealed two cases of the syndrome unnoticed by the patients themselves There are many different theories regarding the etiology The probably correct one is that salivary nerve fibers in the injured facial nerve regenerate in a false direction and reach the lachrymal gland The present investigation which included a study of the mimic function revealed synkinesias in all cases with the syndrome Those without the symptom exhibit a lesser degree of remaining facial paralysis and one third of the cases lack synkinesias In our opinion this supports the theory of misdirected regeneration

INTRODUCTION

The gusto lachrymal reflex means lachrymation in connection with meals It usually appears after a facial paralysis on the affected side Most authors call it the syndrome of crocodile tears This expression was first introduced by Bogorad (1928) The origin of it is given in a footnote by Chorobski (1951) which is cited *in extenso*

The notion that the crocodile a harmful reptile will weep over a man s head after he has devoured the body and then will eat up the head too was the theme of one of the many scientific anecdotes of Pliny the Elder It was popularized in the fourteenth century by the Travels of Sir John Mandeville This gentleman explorer existed only in the imagination of Jean de Bourgogne a French physician who himself never left his country and who charmingly enough confessed that had these fantastic tales he relates been told him he would not have believed them (Legouis E A *History of English Literature The Middle Ages and the Renascence* Vol 1 London J M Dent & Sons Ltd 1948) All that has apparently not deterred (Kroll M *Die neuropathologischen Syndrome zugleich Differentialdiagnostik der Nervenkrankheiten* Berlin J Springer 1929) from believing that the phenomenon an die Tränen erinnert welche das Krokodil beim Verzehren der Beute vergiesst)

Even before Bogorad, Bing (1924, 1932, 1934) used the term "the gusto lachrymal reflex", which is a more adequate and descriptive name It will therefore be used henceforth, abbreviated to g l r

As far as we have found, the syndrome is first mentioned in 1913 in a text book on neurology by Oppenheim, who nevertheless suggests that Engelen and Micas had observed (published?) such cases More than ten years later, the phenomenon was described by Bing in another text book on neurology In 1928 Bogorad gave an extensive report on a case of g l r Since then, in all 67 cases have been published In relation to the frequency of facial paralysis, which usually precedes the appearance of the syndrome, the number of cases of g l r is low This may be due to the fact that the syndrome is a rare sequel to facial paralysis (Chorobski) or that it is not diagnosed and described, since it is probably unknown to most physicians (Dereux, 1953) G l r has many points in common with the gustatory sweating (the auriculo temporal syndrome) that appears after lesions to or operations on the parotid gland Laage Hellman (1957) found this syndrome to appear regularly after parotidectomy, although in most cases in such a minor degree that the patients did not observe it Assuming that g l r is considerably more frequent than the literature indicates, a follow-up investigation of patients, who have been hospitalized for facial paralysis, has been performed in order to demonstrate the frequency of the syndrome

Survey of the literature

All cases of g l r that we have found published have been gathered together in Table 1

The syndrome generally appears as a sequel to a facial paralysis while healing is proceeding There are reports, however, indicating that g l r has been observed at the onset of the paralysis (Kaminsky, 1929 Christoffel 1939) or a considerable time after the paralysis had healed (Sedan 1940, Gottesfeld & Leavitt, 1942, Groff 1947) Boyer & Gardner (1949) describe two cases of g l r that appeared a couple of months after section of the greater superficial petrosal nerve The symptom has also been found together with paralysis of the 6th nerve with or without coexisting facial paralysis (Ehlers, 1932, Viallefont, 1940, Lutman 1947, d Ermo, 1949) Usually the syndrome having once been observed, has persisted Spontaneous disappearance is said to have occurred in a few cases (Bing, 1924, Chorobski, 1951, Bachi 1951) Although gustatory stimulation is the provoking factor, g l r in the particular individual is often provoked by specific sensations of taste, for instance, by salt flavours in some cases, sour substances in others or hot foodstuffs in yet other cases etc (Kaminsky, 1929, Singer & Kellner 1930 Altschul, 1931 Ford, 1933 Russin, 1939 Mutch 1944, d Ermo 1949, Chorobski, 1951, Bachi 1951) Some authors stress that mastication is necessary to provoke the g l r (Singer & Kellner, 1930, Altschul 1931 Christoffel 1939), while others are of the opinion that mastication has no importance and that the chewing of tasteless substances does not lead to

lachrymation (Bogorad 1928, Kaminsky, 1929, Altschul 1931, Ford 1933, Russin 1939, Viallefont 1940, Mutch 1944, d'Ermo 1949, Bachi 1951, Alajouanine & Nick 1953). Some authors state that the patients with g.l.r. do not shed tears on the affected side, when they are weeping (Bogorad 1928, Kroll 1929, Ehlers 1932, d'Ermo 1949). Only Ford (1933) records normal lachrymation in one of his cases. G.l.r. sometimes seems to have been so embarrassing that some kind of treatment has been indicated.

Sédan (1940) describes a tragi-comical case of g.l.r. in a tutor at a lyceum. His duties included having meals with the pupils. On these occasions his eye filled with a flood of tears. This became a permanent joke and his presumed sentimentality was even celebrated in songs by the pupils.

The methods of treatment that have been reported are intended to abolish the secretion either by an extirpation of the lachrymal gland (Tumarkin 1936, Savin 1939) or by a permanent or temporary blocking of the nervous impulses to lachrymation. Several authors successfully performed a blocking of the sphenopalatine ganglion with local anaesthetics and a subsequent injection of alcohol in the ganglion led to favourable and permanent results (Savin 1939, Lutman 1947, Groff 1947). Gottesfeld & Leavitt (1942) also tried this method and obtained positive but transitory results. Boyer & Gardner (1949) successfully treated two cases of g.l.r. which appeared after section of the greater superficial petrosal nerve with intracranial section of the 9th nerve and one case of g.l.r. after facial paralysis with section of the greater superficial petrosal nerve.

The patient with g.l.r. whom Christoffel (1939) describes was more readily treated. He observed that the flood of tears at a meal failed to appear when he forgot to remove his monocle. He therefore continued to keep his monocle on during meals with good results. This method is probably not equally efficient in other cases.

Pathogenesis

Several different explanations of the origin of the syndrome have been published. The most common of these is that after an injury to the secretory nerve fibers to the salivary and lachrymal glands the fibers destined for the salivary gland regenerate in a false direction and reach the lachrymal gland, thus establishing a new reflex arc (Fig. 1*b* and 1*c*). It begins in the taste buds and ends in the lachrymal glands instead of in the salivary glands. Gustatory stimuli that normally give rise to salivation are now able to produce lachrymation. The possible site of a lesion causing g.l.r. is in the facial nerve proximally to the geniculate ganglion, where the lachrymal and salivary fibers run together (Fig. 1*b*). The same condition exists where the greater and smaller superficial petrosal nerves run close to each other (Fig. 1*c*). Bogorad was the first to suggest this genesis of g.l.r. He compares the syndrome with gustatory sweating, which André Thomas (1927) considers to be caused by a similar misdirected regeneration. More recently Ford & Woodhall (1938)

TABLE 1 *Survey of cases of gusto*

Author	Number of cases	Primary lesion	Interval between primary lesion and g l r
Oppenheim 1913	1	Facial palsy (f p)	Late at recovery
Bing 1924	1	Rheumatic f p	
Bogorad 1928	1	F p	
Kaminsky, 1929	2	Postoperative f p Peripheric f p	3 weeks 3 weeks
Singer & Kellner 1930	1	Lues f p	
Altschul 1931	1	Lues f p after salvarsan injection	4 months
Ehlers 1932	1	Complicated delivery with paresis of N VI and f p	
Bing 1932	1	Skull fracture and f p	
Ford 1933	4	Skull fracture and f p Zoster oticus with f p F p Postoperative f p	10 months 6 months 5 months 5 months
Tumarkin 1936	15	Bell s palsy	
Russin 1939	2	Skull fracture and f p F p and epilepsy after injection of neoarsphenamine	A few months 6 months
Christoffel 1939	1	Peripheric f p	No interval
Savin 1939	3	F p F p F p	
Viallefont 1940 46	2	Bilateral f p paresis of N VI and deafness (after meningitis) Bilateral f p a frigore	 A few weeks
Sédan 1940–46	1	F p a frigore	After complete recovery of the paresis
McGovern 1940	1	F p after trauma to the jaw	At recovery
Gottesfeld & Leavitt 1942	1	F p	2 years
Mutch 1944	1	Non traumatic f p	3 months
Lutman, 1947	2	F p and paresis of N VI Bilateral f p and paresis of N VI	
Groff 1947	1	F p	8 10 months after complete recovery of the paresis
d Ermo 1949	2	Syndroma Türk Stilling bilateral Syndroma Türk Stilling	
Boyer & Gardner, 1949	[illegible]	Postoperative f p	6 months
		Section of N petros sf maj Section of N petros sf maj	Several months 4 5 months
Chorobski 1951	1	F p a frigore	[illegible] months
Bachi 1951	2	Zoster oticus and f p Rheumatic f p	25 days A few weeks
James & Russel 1951	[illegible]	Bell s palsy	
Dereux 1953	2	F p a frigore F p a frigore	6 months 3 months
Alajouanine & Nick 1953	1	Skull fracture and f p	6 weeks
Alfandry 1955	1	Zoster oticus and f p	4 10 months
Taverner 1955	6	Bell s palsy	

lachrymal reflex in the literature

Duration of g l r period	Tears when weeping on the affected side	G l r confirmed at examination	Notes
A few months			Spontaneous disappearing of g l r
	–		
18 years	–	+	
3 years		+	
		+	
	–	+	Several other nerve symptoms
17 years			
2 years	+		
2 years			
			No case reports
16 years		+	Synkinesias in the face
			Several other nerve symptoms
4 years			
2 years			
		– bilat	
		+	Cit Baillart
Many years		+	
		+	
8 months		+	
4 years	– bilat		
11 years	–		
1 ½ years			Resection of N petros superfic major with a good result
1 year			Resection of N IX with a good result
			Resection of N IX with a good result
	–		G l r disappeared after several months
19 days		+	G l r disappeared after 3 weeks
		+	
			No case reports
9 years			
13 years			
Less than 1 year			
			No case reports

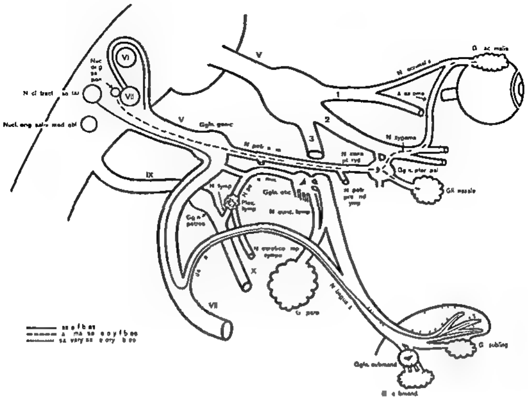

Fig. 1a. Normal pathways for taste, lachrymal and salivary nerve fibres

have discussed this explanation of the syndrome in detail. They refer to a paper by Lipschitz (1906), in which the latter discusses thoroughly the origin of synkinesias after facial paralysis. Lipschitz stressed the important fact that the synkinesias do not appear until voluntary function returns and that only the degree of severity of a facial paralysis is important for the genesis of this phenomenon, which he considers to be due to misdirected regeneration of motor fibres. Nowadays most authors adopt this explanation (Tumarkin 1936, Russin, 1939, Viallefont 1940, Mutch 1944, Groff, 1947, James & Russel 1951, Alajouanine & Nick, 1953, Taverner 1955). In many cases of g. l. r. the patients have increased nasal secretions in connection with gustatory stimulation (Mutch 1944, Taverner, 1955). This nasal secretion may originate—as especially Mutch has stressed—from the eye via the naso-lachrymal duct but also from glands in the nasal mucosa. These glands have the same nervous supply as the lachrymal glands and therefore have the same chance to be reached by a misdirected regeneration. Boyer & Gardner explain their two cases of g. l. r., which appeared after section of the greater superficial petrosal nerve, by stating that the fibres to the parotid gland in the smaller superficial petrosal nerve after section had grown into the lacrymal pathways of the greater superficial petrosal nerve. The fact that section of the 9th nerve led to a disappearance of g. l. r. in these cases argues in favour of the theory (cp. Fig. 1c).

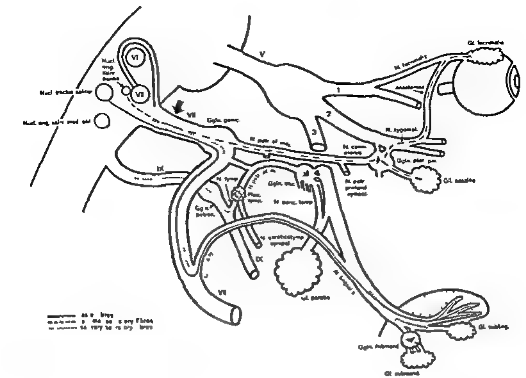

FIG. 1b Abnormal pathways of salivary fibers in a case of gusto-lachrymal reflex due to a lesion situated proximally to the geniculate ganglion

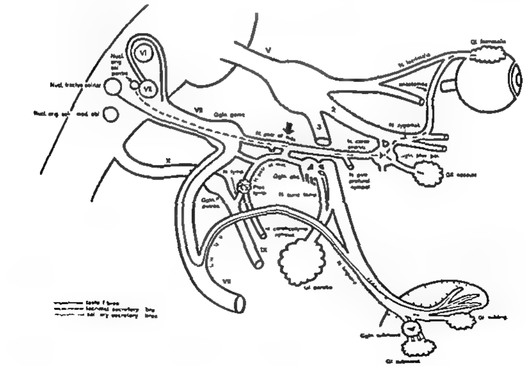

FIG. 1c Abnormal pathways of salivary fibres in a case of gusto-lachrymal reflex due to a lesion situated where the greater and lesser superficial petrosal nerves run close to each other

The other theories are usually described vaguely and they often lack a relation to anatomical and physiological facts. For the sake of completeness, however, some of these will be mentioned. Oppenheim and Kroll interpret the phenomenon as a condition of irritation in the lachrymal pathways. According to Oppenheim it would arise by repeated attempts to innervate the facial muscles via the injured facial nerve. Kroll believes that a connection between gustatory and lachrymal nuclei exists, which is activated by a central irritation after a lesion to the facial nerve. In addition to the theory of misdirected regeneration Bogorad suggests another explanation: in the sympathetic nervous system a widespread irradiation of nerve impulses exists, for instance from salivary nuclei to lachrymal, which normally is inhibited; in cases of facial paralysis this inhibition has disappeared. Kaminsky is of the opinion that because of the lesion of the facial nerve a peripheral neurone is completely disconnected from central control and thus gustatory impulses are *furthered to centrifugal lachrymal paths* at the geniculate ganglion. Ehlers has a similar theory: he thinks that central inhibition disappears, whereupon impulses might pass from gustatory to lachrymal fibres via the geniculate ganglion without reaching the central nervous system. Thus the reflex would be peripheral. Bach is of the opinion that the injured gustatory fibres regenerate faster than the preganglionic parasympathetic lachrymal fibres and that during regeneration the gustatory fibres grow along the greater superficial petrosal nerve to the pterygopalatine ganglion and stimulate the *lachrymal fibres there*. If later on the preganglionic lachrymal fibres regenerate and reach the pterygopalatine ganglion, the postganglionic nerves will not be influenced by gustatory impulses any longer, which explains the cases of transitory g.l.r. Bing (1934) and Grobin seem to be inclined to interpret g.l.r. as an effect of denervation in conformity with the paralytic secretion that appears in the salivary glands. Chorobski, who has given a detailed and thorough account of g.l.r. and particularly its pathogenesis, believes that the symptom arises through a cross stimulation in scar tissue in which there are salivary as well as lachrymal fibres. Impulses in salivary fibres would give rise to impulses in the peripheral lachrymal fibres. Lutman and d'Ermo have published cases of g.l.r. in combination with paralysis of the 6th nerve but without facial paralysis. Lutman assumes that the syndrome in these cases is due to a lesion in the pons.

PRESENT INVESTIGATION

Material

One hundred and eighteen adults treated for facial paralysis in the years 1949–1958 in the Department of Oto-rhino-laryngology, Sahlgrenska Hospital, Gothenburg, were summoned by letter to examination. Eighty-two of these were examined. Among those not examined 5 are dead, 10 are of unknown address and 21 have not been able to come or have not answered the letter. According to the genesis of facial paralysis the entire material

TABLE 2 *Present material Relation to the etiology of facial paralysis*

		Examined	Not examined	Total
Traumatic	Skull fracture	25 (21 ♂, 4 ♀)	9 (9 ♂)	34 (21 ♂, 13 ♀)
	Surgery	5 (4 ♂, 1 ♀)	2 (2 ♀)	[illegible] (4 ♂, 3 ♀)
Non traumatic	*Bell s palsy*	28 (15 ♂, 13 ♀)	15 (6 ♂, 9 ♀)	43 (21 ♂, 22 ♀)
	Herpes zoster	12 (5 ♂, 7 ♀)	2 (1 ♂, 1 ♀)	14 (6 ♂, 8 ♀)
	Otogenous infection	12 (7 ♂, 5 ♀)	8 (5 ♂, 3 ♀)	20 (12 ♂, 8 ♀)
Total		82 (52 ♂, 30 ♀)	36 (21 ♂, 15 ♀)	118 ([illegible]3 ♂, 45 ♀)

may be divided into two main groups traumatic and non traumatic and subgroups of these according to Table 2

Method of Investigation

The patients were first questioned about symptoms following the healing of the paralysis If they did not mention anything about disturbances in the lachrymal or nasal secretion they were questioned directly if weeping occurred at meals The condition of lachrymation while weeping was also inquired for An examination of the mimic function was performed and the persistent paralysis if any was graded Presence of synkinesias and contracture of the facial muscles were noted The secretion of tears was examined by Schirmer s method (1903) a strip of filter paper is placed in the lower eyelid and the amount of secretion is determined by measuring the damp part of the filter paper The secretion during one minute was first recorded Then gustatory stimulus was given by having the patient suck slices of lemon or grape fruit for at least two minutes The lachrymation was simultaneously recorded If the mechanical irritation caused by the paper gave rise to a severe lachrymation the conjunctiva was anaesthesized whereupon renewed measuring was performed

The taste was tested separately on each half of the tongue with electric stimulation and with the four basic taste substances

RESULTS

Nine patients mentioned spontaneously and 7 on a direct question or renewed contact that they had observed lachrymation at meals (Table 3) While weeping [illegible] of these 16 patients had observed dryness on the affected side In general it was difficult for the patients to state when g l r had appeared after the facial paralysis The statements range from onset early during the time of paralysis to a long time after healing Six patients said that g l r appeared at every meal and the same number stated that the symptom was variable A period of latency varying between one to ten minutes

The other theories are usually described vaguely and they often lack a relation to anatomical and physiological facts For the sake of completeness however, some of these will be mentioned Oppenheim and Kroll interpret the phenomenon as a condition of irritation in the lachrymal pathways According to Oppenheim it would arise by repeated attempts to innervate the facial muscles via the injured facial nerve Kroll believes that a connection between gustatory and lachrymal nuclei exists which is activated by a central irritation after a lesion to the facial nerve In addition to the theory of misdirected regeneration Bogorad suggests another explanation in the sympathetic nervous system *a widespread irradiation of nerve impulses* exists for instance from salivary nuclei to lachrymal which normally is inhibited in cases of facial paralysis this inhibition has disappeared Kaminsky is of the opinion that because of the lesion of the facial nerve a peripheral neurone is completely disconnected from central control and thus gustatory impulses are furthered to centrifugal lachrymal paths at the geniculate ganglion Ehlers has a similar theory he thinks that central inhibition disappears whereupon impulses might pass from gustatory to lachrymal fibres via the geniculate ganglion without reaching the central nervous system Thus the reflex would be peripheral Bachi is of the opinion that the injured gustatory fibres regenerate faster than the preganglionic parasympathetic lachrymal fibres and that during regeneration the gustatory fibres grow along the greater superficial petrosal nerve to the pterygopalatine ganglion and stimulate the lachrymal fibres there If later on the preganglionic lachrymal fibres regenerate and reach the pterygopalatine ganglion the postganglionic nerves will not be influenced by gustatory impulses any longer which explains the cases of transitory g l r Bing (1934) and Grobin seem to be inclined to interpret g l r as an effect of denervation in conformity with the paralytic secretion that appears in the salivary glands Chorobski who has given a detailed and thorough account of g l r and particularly its pathogenesis believes that the symptom arises through a cross stimulation in scar tissue in which there are salivary as well as lachrymal fibres Impulses in salivary fibres would give rise to impulses in the peripheral lachrymal fibres Lutman and d Ermo have published cases of g l r in combination with paralysis of the 6th nerve but without facial paralysis Lutman assumes that the syndrome in these cases is due to a lesion in the pons

PRESENT INVESTIGATION

Material

One hundred and eighteen adults treated for facial paralysis in the years 1949 1958 in the Department of Oto rhino laryngology Sahlgrenska Hospital Gothenburg were summoned by letter to examination Eighty two of these were examined Among those not examined 5 are dead 10 are of unknown address and 21 have not been able to come or have not answered the letter According to the genesis of facial paralysis the entire material

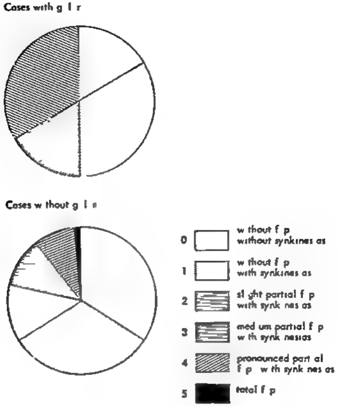

Fig. 2. The presence of synkinesias and the degree of remaining f p in cases with and without g l r.

After gustatory stimulation only 4 of the 16 patients with subjective g l r showed a more pronounced secretion on the affected side. Four other patients indicated a tendency to a more profuse secretion on the affected side, while the remaining ones did not show any objective signs of g l r. Among those who denied lachrymation at meals there were 2 cases in which the examination showed an increased lachrymation on the previously paralysed side. Table 3 presents the distribution of the cases of g l r with regard to the etiology of the facial paralysis and the degree of remaining paresis. The table also shows that synkinesias occurred in all cases of g l r. For the sake of comparison it may be mentioned that among the 64 cases without g l r 23 have no synkinesias. Fig. 2 presents the distribution of the frequency of synkinesias and the degree of remaining paralysis in cases with and without g l r.

The examination of the taste gave results so uncertain that they are not worth analysis.

Two case histories will be given, one rather typical, the other more unusual.

Case no. [illegible] (Fig. 3)

A left sided facial palsy appeared after three days' headache. No abnormalities except the facial paralysis were found. Spinal fluid was normal. Subsequently the

TABLE 3 *Present material Cases with gusto lachrymal reflex*

Degree of facial paralysis (f p) 0 without f p, without synkinesias 1, without f p, with synkinesias [illegible] slight partial f p with synkinesias 3 medium partial f p with synkinesias 4 pronounced partial f p with synkinesias

Case No	Sex	Age at onset of f p	Etiology of f p	Presence of g l r given: Spontaneous	Presence of g l r given: On question about lachrymation disorder	Tears when weeping on the affected side	Degree of persisting f p	Synkinesias	G l r confirmed at the investigation
1	♂	44	Skull fracture	+		?	2	+	−
2	♀	27	Zoster oticus	+		Yes	2	+	−
3	♂	40	Bilateral Melkerson's syndrome	+		?	1 bilat	+	+
4	♂	2	Injection of alcohol in Ggln Gasseri		+	?	3	+	?
5	♂	[illegible]	Skull fracture			?	1	+	+
6	♂	20	Bell's palsy	+		?	2	+	+
7	♀	70	Bell's palsy		+	?	4	+	?
8	♀	57	Bell's palsy		+	?	3	+	?
9	♂	62	Zoster oticus		+	None	4	+	−
10	♀	32	Bell's palsy		+	?	4	+	−
11	♀	37	Skull fracture	+		None	2	+	?
12	♀	22	Skull fracture	+		?	2	+	+
13	♂	65	Skull fracture		+	?	[illegible]	+	+
14	♂	5	Traumatic f p after flash stroke			?	4	+	+
15	♀	71	Zoster oticus		+	?	4	+	−
16	♂	25	Skull fracture	+		?	4	+	−
17	♂	30	Skull fracture	+		?	1	+	−
18	♀	16	Bell's palsy	+		None	3	+	−

was noticed before the tears appeared Seven patients said that all kinds of food and 6 that acid substances might provoke symptoms of g l r Hot food was more apt than cold food to produce the symptom in 6 patients, but on the other hand one found cold food more apt than hot food Eleven patients said that mastication was necessary to provoke g l r Four patients had experienced increased nasal secretion at meals No more than 2 patients considered the syndrome troublesome

Fig. 1. Case of g.l.r. Melkersson's syndrome + acromegaly.

cases with slight symptoms. It is not possible for us to state which of these two facts is the right one, but our experience from Schirmer's test has clearly indicated that the method is not very sensitive. Unfortunately there are very few quantitative methods for recording lachrymal secretion. Many authors state that, among the available methods, Schirmer's test is the best one for clinical use, because it admits a comparison with the other side (Blümel 1949, Illge & Ruoff 1956, de Roetth 1952, Szmyt 1958). There are more accurate methods, for instance, collection of lachrymal secretion through catheters in the lachrymal duct (Rosengren 1927), but such tests are too complicated and troublesome for the patient to be used as a routine. In spite of the fact that we have a critical attitude to Schirmer's test, we have included in our material 2 patients who probably suffer from g.l.r., though they have not themselves observed increased lachrymal secretions at meals.

Our investigation indicates a rather high frequency of g.l.r. after facial paralysis, but not as high as Lumarkin reported: 15 (or 13) of 44 cases of Bell's palsy. James & Russel (1951) found 6 cases among 58 and Taverner (1955) 6 cases among 100 of Bell's palsy (cp. 4 cases of 28 in the present material).

According to the present investigation, g.l.r. appeared after herpes zoster oticus with facial paralysis, Bell's palsy, skull fracture with facial paralysis and in one case after an injection of alcohol in the Gasserian ganglion followed by deafness and transitory facial paralysis. On the other hand g.l.r. did not appear after facial paralysis caused by surgery in the middle ear. This may be due to the fact that the facial nerve is injured peripherally to the point where the lachrymal fibres leave the nerve. The number of cases, however, is only 5. G.l.r. was not observed in the 12 cases of facial

ralysis in connection with acute or chronic otitis media probably due the fact that the injury to the nerve has been slight The paralysis rapidly bsided in only 3 cases did a slight partial paralysis persist and synkinesias peared in 5 out of 12 cases

G l r does not usually give rise to any inconvenience for the patient It is ie however that some of them expressed a certain amount of surprise at : bizarre phenomenon but only 2 patients complained Treatment with anticholinergic drug orally in one case did not give any relief

Our investigation cannot make any real contribution to the explanation the etiology of the syndrome but in our opinion the relation between nkinesias remaining paralysis and g l r argues in favour of the theory regeneration It is worth noting that all cases of g l r have synkinesias ile one third of the cases without g l r do not have this symptom Experi entally and clinically it is well confirmed that severed nerve fibres may ow out and establish a functional unit with end organs different from the ginal ones This is true not only for motor fibres growing out to the wrong iscle but also for secretory fibres that may grow out to a different gland d create a functional unit when the transmitter substance at the nerve dings is identical in both glands The fact that some patients stated that : syndrome disappeared contradicts the theory of misdirected regeneration ing 1924 Chorobski 1951 Bachi 1951) As long as objective evidence this disappearance is lacking it is necessary to maintain a sceptical attitude vards this statement Like those suffering from gustatory sweating the tient may believe that the syndrome has disappeared although it still nains (Lange Hellman 1957) Sometimes the patients with g l r assign a ort interval from the onset of the facial paralysis to the appearing of the idrome which also contradicts the theory of misdirected regeneration nclusions may not be drawn from statements concerning the period of ency since the patient himself cannot possibly distinguish the g l r from : epiphora that is often present at the beginning of a facial paralysis

In the literature several cases of g l r are reported in which the patient's hrymation on the affected side fails to appear when he is weeping Three our patients have noticed the same A possible explanation is that the retory cells in the lachrymal gland are reached mainly by salivary fibres Although the theory of misdirected regeneration appears to be the best planation of g l r Chorobski's theory of cross stimulation cannot be re ted Maybe both theories are valid The other theories previously men ned need no further discussion since in our opinion they lack a basis the currently accepted anatomical and neurophysiological facts In the ses with g l r and coexisting paralysis of the 6th nerve and other neurologi symptoms one may assume a lesion in the central nervous system settle the etiology a reliable easily tolerated method for measuring hrymal secretion is required Such a method might help us to determine frequency of g l r after facial paralysis the period of latency and the ther course It would even be possible to study the influence of different

pharmacological agents on the affected and healthy sides Furthermore, it would be interesting to reverse the problem and in cases of g l r study the salivation during emotional weeping

ZUSAMMENFASSUNG

Unter dem gustolakrimalen Reflex versteht man einen während des Essens sich einstellenden Tränenfluss Er tritt auf bei Facialisparesen auf der erkrankten Seite In der Literatur sind 67 Fälle beschrieben Wir vermuteten, dass das Syndrom häufiger vorkommt (als wie es durch diese Ziffer angedeutet wird) und führten Nachuntersuchungen bei 118 erwachsenen Patienten, die unter einer Facialisparese litten, durch Von 82 untersuchten Patienten hatten 16 während des Essens Tränenfluss beobachtet Um die Tränensekretion zu messen, wurde der Schirmer'sche Test angewandt Dieser Test schien uns für unseren Zweck am besten, wenngleich er auch nicht ganz zuverlässig ist Trotz der Unzuverlässigkeit der Methode glauben wir auf diese Weise 2 Patienten, die das Symptom selbst nicht bemerkten, einen gustolakrimalen Reflex entdeckt zu haben Hinsichtlich der Ätiologie gibt es verschiedene Theorien Die wahrscheinlich richtige Theorie ist die, dass die salivatorischen Nervenfasern im geschädigten N facialis in falscher Richtung regenerieren und die Tränendrüse erreichen Die vorliegende Untersuchung, welche auch ein Studium der mimischen Funktionen einschloss, zeigte, dass sich in allen Fällen Synkinesien mit dem gustolakrimalen Reflex fanden Diejenigen Fälle, welche das Syndrom nicht aufwiesen hatten zu einem Drittel keine Synkinesien und zeigten dabei nur einen geringen Paresegrad Unserer Meinung nach stützt dies die Theorie von der fehlgerichteten Regeneration

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Alf Axelsson, Lasarettet, Ma
J.-E. Laage-Hellman, Lasarettet, Sun

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BEOBACHTUNGEN ZU GEHÖRVERBESSERNDEN OPERATIONEN BEI CHRONISCH MESOTYMPANALEN OTITIDEN[1]

PAUL BECKERT
Freiburg/Br. Deutschland

Aus der Universitätsklinik für Hals-, Nasen- und Ohrenkranke (Dir. Prof. Dr. F. Zöllner), Freiburg/Br.

Die Unterteilung der verschiedenen Typen bei der Tympanoplastik in ihre Charakteristik „a" und „b" sind noch nicht allgemein bekannt. Die statistische Auswertung rechtfertigt diese besondere Kennzeichnung. Beim freien Transplantat wird ferner über das verschiedene Material, das zum Ersatz des Trommelfelles Verwendung findet, seine Vor- und Nachteile berichtet. Dann werden *spezielle Beobachtungen bei den Typen II, III und IV* mitgeteilt und abschließend auf das postoperative Verhalten der Knochenleitungsschwelle eingegangen.

Chronisch mesotympanale Mittelohreiterungen führen in der Regel zur Schalleitungsschwerhörigkeit. Die operativen Eingriffe, die der Wiederherstellung des Gehörs dienen, müssen deshalb in den Heilplan miteinbezogen werden. Durch die systematische Entwicklung und Darstellung dieser Operationen von Wullstein (16) und Zöllner (18) haben die Verfahren rasch ein weltweites Echo ausgelöst und das nachdrückliche Interesse der führenden Otologen gefunden.

Die Eingriffe, die als „Tympanoplastik" bezeichnet werden, sind mittlerweile vielfach erprobt, haben, abgesehen von den Grundprinzipien der Schallübertragung, doch in der Technik und der Art des verwendeten Materials inzwischen Abwandlungen erfahren. Hierüber und über einige Erfahrungen soll kurz berichtet werden.

ALLGEMEINE BEMERKUNGEN

Eine zusätzliche Differenzierung der Typeneinteilung in „a"- und „b"-Fälle, wie dies Zöllner vorschlägt, wobei der jeweilige Typ „a" einer Plastik mit freiem Transplantat entspricht, einer mit der Bezeichnung „b" anzeigt, daß hier Trommelfellreste zur Plastik verwendet wurden, ist nicht allerorts geläufig. Die statistische Auswertung hat diese Unterscheidung jedoch gerechtfertigt. Soweit wir Trommelfellstrukturen für die Plastik verwenden

[1] Vortrag gehalten auf dem Kongreß der Ungarischen Oto-Rhino-Laryngologen am 5. 10. 1961 in Budapest.

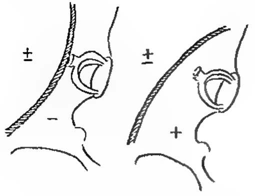

Abb. 1

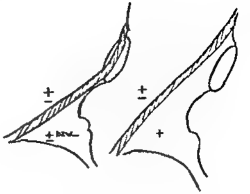

Abb. 2

Abb. 1. IIIa Plastik. a) Transplantat liegt bei Unterdruck in der Pauke dem Stapeskopf an. b) Transplantat bei Überdruck in der Pauke vom Stapeskopf abgehoben: sofortiger Hörverlust.
Abb. 2. IVa Plastik. a) Transplantat liegt bei Unterdruck in der Pauke direkt über der Fußplatte. b) Transplantat wird bei Überdruck in der Pauke von der Fußplatte abgehoben und bezieht die ganze ovale Fensternische in den lufthaltigen Raum der Pauke ein: sofortiger Hörverlust.

können, sollten diese ausgenutzt werden. Solche Plastiken ergeben zweifellos die dauerhaftesten Resultate. Häufig bietet sich für den Operateur ein solches Vorgehen für die Plastiktypen III und IV an; nicht selten entstehen sie im Verlauf einer natürlichen Abheilung von selbst. Der freie Plastiklappen hat dagegen sehr häufig Anpassungsschwierigkeiten, die früher oder später zu Perforationen oder vollständigen Zerstörungen durch Randablösungen, zentrale Ernährungsstörungen oder durch Lappencholesteatome führen (1, 16, 18). Die Angaben über die sofortigen und späteren Sekundär-Perforationen nach Tympanoplastiken sind noch sehr unterschiedlich und schwanken zwischen 6 und 30%.

Es ist verständlich, wenn man nach einem weniger empfindlichen Material für das Transplantat Ausschau gehalten hat, das wenigstens einen Teil der möglichen Störungen von vornherein vermeiden läßt. So wurde versucht, die Anpassungsschwierigkeiten des Hautlappens durch Verwendung von konservierter Homovo-Transplantate (Burian), von epithelfreier Unterhaut (Link), Faszie (Heermann, Zöllner), Periost (Claros Domenech) oder Vene (Shea) zu verwenden. Alle die ebengenannten Gewebe scheinen sich für den plastischen Verschluß am Trommelfell zu eignen. Die im Vergleich zur Epidermis an und für sich bradytrophen Gewebe haben verschiedene Vorteile, die es angezeigt sein lassen, größere Versuchsreihen anzustellen. Diese Vorteile können kurz folgendermaßen umrissen werden:

1) kann es nicht zu Lappencholesteatomen kommen.

2) entfällt das Erfordernis, vom Trommelfellrest bzw. — bei großen Perforationen — vom Annulus und dessen angrenzendem häutigen Gehörgangsschlauch das Epithel entfernen zu müssen, da das transplantierte Gewebe von innen her auf die angefrischte Schleimhaut des Trommelfellrestes gelegt wird. Damit sind die nicht seltenen Sekundärcholesteatome, die zwischen

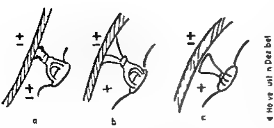

Abb. 3 a, b, c

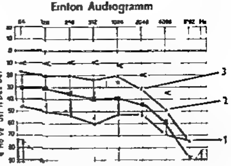

Abb. 3 d

Abb. 3. III a Plastik. a) Stapeskopf mit Transplantat durch Bindegewebsstränge locker verbunden. b) bei Überdruck im Mittelohr Anstraffen der Bindegewebsstränge und deutlicher Hörgewinn. c) Columella, die fest mit Transplantat verwachsen, aber mit der Fußplatte nur durch Bindegewebsstränge verbunden ist; bei Überdruck im Mittelohr deutlicher Hörgewinn. d) Audiogramm. 1 Schwelle vor der Operation. 2 Schwelle, wenn Stapeskopf bzw. Columella nur durch Bindegewebsstränge locker mit Transplantat bzw. Fußplatte verbunden sind. 3 Schwelle nach Valsalva. Durch Überdruck in der Pauke Anstraffen der Bindegewebsstränge zwischen Transplantat und Stapeskopf bzw. Columella und Fußplatte.

Annulus tympanicus und aufgesetztem Transplantat vorn unten entstehen, ausgeschlossen.

3) wird die Perforation bei der Vorbereitung zur Einlage nicht größer, da der callöse Rand des Trommelfells nicht ausgeschnitten, sondern nur das eingeschlagene Epithel nach außen gekrempelt werden muß. Die Perforation wird dabei von vornherein schon kleiner, und die dünnen Epithelränder legen sich gut auf das eingepaßte Transplantat.

Wir verfügen noch nicht über größere Reihen, die statistisch ausgewertet werden können, aber mit Venen lassen sich, wie wir gesehen haben, recht günstige Ergebnisse erzielen, ebenso mit Bindegewebe. Beide Materialien benötigen allerdings eine Umbauzeit von 2–3 Monaten, um dann zu sehr schönen, zarten Trommelfellen zu führen. Da alles Stützgewebe ontogenetisch vom Mesoderm abstammt, und zwar vom Mesenchym, bringt es die genetische Verwandtschaft mit sich, daß innerhalb der Stützgewebe Formumwandlungen des differenzierten Gewebes möglich sind (13).

Spezielle Beobachtungen zur Tympanoplastik Typ II, III und IV

Der Plastiktyp III hat zweifellos die meisten Aussichten, eine Störung seines funktionellen Dauerergebnisses zu erleiden (2). Bei flacher Pauke neigt das Transplantat zu Verwachsungen. Bei schmaler und tiefer Pauke tendiert das Transplantat, selbst wenn es spannungsfrei eingelegt wurde, dazu, sich vom Kopf des Stapes wieder abzuheben. Schon bei der Nachbehandlung einer solchen Tympanoplastik nach Typ III kommen wir in ein gewisses Dilemma. Was für die flache Pauke gut ist — ein baldiges

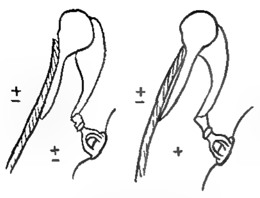

Abb. 4 a, b

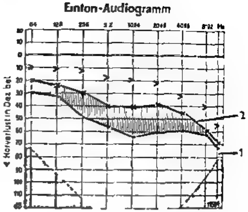

Abb. 4 c

Abb. 4. a) Amboß-Stapes-Gelenk durch Zerstörung des distalen Endes des langen Amboßschenkels unterbrochen, Gehörbeine hängen nunmehr durch Bindegewebsstränge locker zusammen. b) Durch Überdruck in der Pauke Anstraffen der Bindegewebsstränge und deutlicher Hörgewinn (Spannungsphänomen). c) Audiogramm: 1, Schwelle bei normal belüfteter Pauke, 2, Schwelle bei Überdruck in der Pauke

Belüften der Pauke, Überdruck durch Valsalva oder Politzer'sche Luftdusche, um Verklebungen zu vermeiden — unterstützt bei der schmalen, tiefen Pauke u. U. die Ablösung des Transplantates. Ist die Ablösung des Transplantates vollkommen, so werden wir auf die Luftdusche keinen Gewinn sondern eher eine Hörverschlechterung bekommen (Abb. 1), ebenso wie in den seltenen Fällen der sonst so verhältnismäßig sicheren Tympanoplastik des Typs IV, in denen das Transplantat das ovale Fenster überwachsen hat, es nach Lufteinblasen pneumatisiert und in den lufthaltigen Raum der kleinen Pauke miteinbezieht (Abb. 2). Legt sich das Transplantat in solchen Fällen durch Unterdruck, z. B. beim Kauen oder beim Toynbee'schen Versuch, im Falle des Typs III wieder auf den Stapes, im Falle des Typs IV wieder auf das ovale Fenster, steigt das Gehör an.

Bei Typ III kann es zu folgender besonderen Konstellation kommen. Die Pauke ist gut belüftet, das Gehör hat sich jedoch verschlechtert, steigt aber bei Überdruck im Mittelohr wieder an. Diese Eigentümlichkeit tritt dann ein, wenn sich das Transplantat vom Stapeskopf gelöst hat, aber durch lockere Bindegewebsstränge noch damit verbunden ist. Durch das Anstraffen der Stränge kommt es dann zur besseren akustischen Übertragung (Abb. 3). Diese Beobachtung, von uns als „Spannungsphänomen" bezeichnet, haben wir vor Jahren schon (Sch.—7/1435/56, H.—7/1773/56) bei Patienten mit Zerstörung des Stapes-Amboß-Gelenkes, aber mit Erhaltung eines Bindegewebsstranges zwischen Stapeskopf und Amboß gesehen (Abb. 4); aber auch dann, wenn das Trommelfell als Spontanplastik mit dem Stapeskopf durch Bindegewebsstränge verbunden war. Ähnliche Befunde konnte Zöllner (19) nach frei zwischen Fußplatte und Transplantat eingesetztem Knochenstift erheben. Heermann (7) hat kürzlich über entsprechende Beobachtungen nach Stapesplastik und

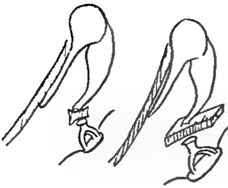

Abb. 5

Abb. 6

Abb. 5. Verbindung zwischen verkürztem langen Amboßschenkel und Kopf des beweglichen Stapes durch Knochenstift oder Knochenplatte wieder hergestellt

Abb. 6. Columellisation bei IIIa Plastik. a) Knochenspan auf Stapeskopf. b) umgeschliffener Amboß auf Stapeskopf. c) Amboß zwischen Fußplatte und Transplantat

Tympanoplastik mit Bindegewebsinterposition berichtet. Um solchen unerwünschten Entwicklungen beim Verschluß der flachen oder schmalen und tiefen Pauke entgegenzuwirken, übt Zöllner (19) schon seit längerer Zeit die sog. „Columellisation" bei der Plastik des Typs III. Durch Zwischenschaltung eines Knochenspanes oder Knochenstiftes zwischen Stapeskopf und Transplantat wird der Stapes verlängert (Abb. 6). Der Luftraum in der Pauke wird dadurch vergrößert, das Transplantat liegt — entsprechend weit von der Paukenwand entfernt — ohne Spannung der Columella an. Es kommt daher weniger zu Verklebungen, und der hohe Luftraum läßt eine bessere Anhebung der unteren Frequenzen erwarten (11). Eine Columellisation kann auf verschiedene Weise bewerkstelligt werden. Da Zöllner körpereigenes Gewebe bevorzugt, verwenden wir gern einen Knochenstift aus dem Planum mastoideum (19) oder einen Knochenspan, wie er sich auch bei der Stapedektomie mit dem von Zöllner und Beickert angegebenen Meißel nach Auslösen des Trommelfells leicht aus der überhängenden hinteren Gehörgangswand gewinnen läßt. Auch Teile vorhandener Gehörknöchelchen (5), die u. U. umgeschliffen werden, sind sehr nützlich. Utech (14) verwendet Knorpelstücke, sog. „Mobilknorpel". Müssen große Abschnitte oder das ganze Trommelfell ersetzt werden, so ist es günstig, die Columella so zu gestalten, daß sie einem „Kragenknopf" gleicht, der mit seinem schmalen Teile auf dem Stapeskopf ruht, mit einem ausladenden Teil aber als Stütze für das neue Transplantat dienen kann. Im selben Sinne wird verfahren, wenn nurmehr die bewegliche Fußplatte vorhanden ist. In manchen Fällen wird man in 2 Sitzungen operieren, nämlich die Situation im Mittelohr klären, die Pauke verschließen und in einem 2. Akt, der dann enaural durchgeführt werden kann, die Columellisation in 2–3 Monaten folgen lassen.

Die Beteiligung des Innenohres bei der Tympanoplastik

Auf der Tagung in Baden-Baden 1957 konnten wir (1) schon auf die kritische Situation des bleibenden, postoperativen Abfalls der Knochenleitung, besonders in den oberen Frequenzen, hinweisen. Wie sich gezeigt hat, sind wir vor einer solchen Komplikation nie sicher, sie tritt völlig unmotiviert, gerade auch beim Typ I, beim reinen Trommelfellverschluß, bei trockener Pauke ein, bei der die Fenstergegend überhaupt nicht berührt worden ist. Wir haben dabei sogar eine Ertaubung erlebt. Heermann (6) gibt für sein Material bei Tympanoplastiken in 5% Ertaubungen bzw. hochgradige Innenohrverluste an. Wenn solche Innenohrverluste erst sekundär auftreten, — wir sehen dies bei vernachlässigten Höhlen, die verschmutzt und mit Epithelmassen ausgefüllt sind —, weist uns das nur nachdrücklich darauf hin, daß die operierten Ohren regelmäßigen Kontrollen zugeführt werden müssen.

Etwas ganz anderes ist der vorübergehende Abfall der Knochenleitung nach der Operation. Es ist dies nichts Außergewöhnliches, ein Vorgang, der uns bei der Stapedektomie schon lange bekannt ist. Der Knochenleitungsabfall beginnt meist bei 1000 Hz, um in den oberen Frequenzen ganz erhebliche Werte anzunehmen. Bei Stapedektomien sehen wir in den ersten Tagen solche temporäre Knochenleitungsverschlechterungen zwischen 15 und 40 db in 50–60% der Operierten, bei Plastiken entsprechend in 30–50%, geprüft jeweils an 50 nichtausgewählten aufeinanderfolgenden Fällen. Beim Vergleich zwischen einfachen Radikaloperationen, Tympanoplastiken und Stapedektomien, wird es klar, daß es sich nicht einfach um eine Vertaubungserscheinung handeln kann, sondern daß es sich wahrscheinlich um eine vorübergehende seröse Labyrinthitis handelt, evtl. auch um die Wirkung des Lokalanästhetikums (9), wobei Letzteres noch einer genaueren Untersuchung bedarf. Die Erscheinungen sind auch keineswegs gesetzmäßig. Wir haben z. B. einen zeitweiligen Knochenleitungsverlust von 30–40 db nach einem Mobilisationsversuch beobachtet und später, bei der Stapedektomie, am selben Ohr überhaupt keine postoperativen Veränderungen an der Knochenleitung feststellen können. Das Umgekehrte haben wir auch schon gesehen. Dieser temporäre Abfall der Innenohrleistung geht im allgemeinen nach 8 Tagen, in Ausnahmefällen innerhalb 3 Monaten, wieder zurück, und die Knochenleitung erreicht die Voroperationswerte wieder (2). Es kann aber auch etwas sehr Erfreuliches eintreten. Manchmal wird die präoperativ nach höheren Intensitäten verschobene Knochenleitungskurve postoperativ gebessert, d. h. die Knochenleitungswerte liegen günstiger als die vor der Operation gemessenen. Dies besagt nun, daß auch beim schalleitungsgestörten Ohr die Knochenleitungsschwelle keineswegs immer die tatsächliche Innenohrreserve angibt, wir also in den präoperativ ermittelten Knochenleitungswerten nicht die absolute Innenohrreserve sehen dürfen, wie wir das bisher gewohnt waren.

SUMMARY

The classification of the different types of tympanoplasty in their characteristics "a" and "b" is not yet generally known. Yet statistical evaluation justifies this special codification. Various kinds of material for replacement of the tympanic membrane by using free grafts and their respective usefulness and disadvantages are discussed. In addition, specific observations concerning the types II, III and IV are communicated and, finally, the postoperative condition of the bone conduction threshold is described.

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Universitatsklinik f. HNO, Hugstetterstr. 59, Freiburg Br.

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STAPESERSATZ DURCH KNORPEL

CLAUS JANSEN
Gummersbach, Deutschland

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Nach den Mobilisationen und punktförmigen Fensterungen in der Fußplatte durch Rosen kam es zu Teilresektionen der Fußplatte und Steigbügelköste von Shea, Fowler, Shambaugh, Clerc, Heermann, Schubert, Zöllner, Zangemeister, Goodhill, Holmgren, Portmann, Antoli Candela, Meurmann u. a. Im weiteren Verlauf der Entwicklung wurde die totale Stapedektomie bei entsprechender Indikation eingeführt, wobei zur Deckung des ovalen Fensters Cutis, Venenwand oder Bindegewebe verwandt wurde. *Die notwendige Wiederverbindung mit dem langen Amboßschenkel kommt* durch Verwendung des gesamten (Portmann) oder Teilstückes des Steigbügels zustande. Von Shea wird dazu ein Kunststoffröhrchen, von Schuknecht Tantaldraht, von Zangemeister, Heermann, Schubert, Zöllner u. a. Bindegewebe interponiert. Diese Methoden haben sehr gute Erfolge vor allem auch auf längere Zeit hin erbracht, wobei sich allerdings in zunehmendem Maße in letzter Zeit Bedenken gegen die Verwendung des Polyaethylenröhrchens als Kunststoff sowohl auch in seiner Anwendungsform ergeben haben. Dasselbe gilt für die Verwendung des Tantaldrahtes. Boenninghoff, Kley, Zöllner, Weber und andere berichten von Durchspießungen durch die Venendeckung des ovalen Fensters, von Nekrosen am langen Amboßfortsatz, Abrutschen aus der Lagerung am langen Fortsatz und die jederzeit bestehende Möglichkeit einer Fremdkörperreaktion. Von den möglichen Gefahren in dieser Richtung abgesehen erscheint jedoch auch ein Hinweis auf die physiologischen Bewegungen des Stapes, auch in Bezug auf andere Operationsmethoden wichtig. Während es normalerweise zur posterior-anterioren einerseits, zur seitlichen Kippbewegung andererseits kommt, ist dies bei den meisten Methoden nicht oder nur in verschwindendem Maße möglich. Bei Wiederverwendung einer Stapeshälfte oder Teile desselben und auch bei Einsetzen eines Kunststoffröhrchens geht, wie nebenstehende schematische Abbildungen zeigen, ein Teil des Schalldrucks durch Konterbewegung der Perilymphe in die Venendeckung des ovalen Fensters hinein verloren. Andererseits kommt die seitliche Bewegung nur in geringem Umfang zur Wirkung, weil das ovale Fenster nur noch zu einem Bruchteil gegenüber der normalen Fußplatte ausgefüllt ist und die elastische Venendeckung der seitlichen Kippbewegung nicht folgt.

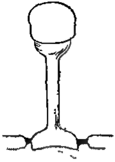
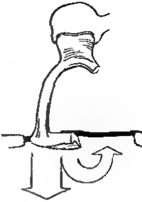


Abb. 1

Abb. 2



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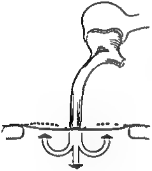

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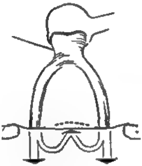

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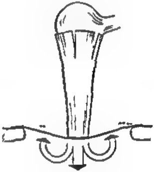

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Abb. 11

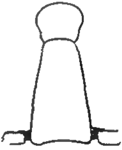

Abb. 12

Abb. 1 und 2 Die physiologischen posterior-anterioren und seitlichen Bewegungen des Steigbügels

Abb. 3, 4 und 5 Die Ausweichbewegung der Perilymphe und der elastischen Deckung des ovalen Fensters

Abb. 6 und 7 Bewegungsablauf in posterior-anterior und seitlicher Richtung bei Einsetzen eines Kunststoffröhrchens

Abb. 11 und 12 Schematische Darstellung des Knorpelstapes in zwei Ebenen

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Diese Mängel können eine Erklärung sein für die Erfahrungstatsache, daß bei gutem Tongehörgewinn die Sprachverständlichkeit noch nicht entsprechend ist.

Der Einwand, daß es zu einer Vernarbung und damit zu einer Verhärtung der Fensterdeckung komme, scheint nicht gegeben, da bei einer Bewegung der Membran im ovalen Fenster von oben dieselbe Möglichkeit von unten aus besteht. Bevor also das runde Fenster in Funktion treten kann, weicht die Perilymphe — da nicht komprimierbar — nach oben hin aus und ein Teil des Schalldrucks geht verloren. Die Interpositionsmethode mit Subcutis hat den Vorteil des autoplastischen Materials und es kommt auch wegen der massiveren Deckung des ovalen Fensters nicht in dem Maße zu Schalldruckverlusten durch Konterbewegungen der Perilymphe; jedoch ist eine Reaktion im physiologischen Sinne kaum vorstellbar, da ja im Gegensatz zum knöchernen Steigbügel lediglich eine elastische narbige Verbindung zwischen langem Fortsatz und ovalem Fenster entsteht.

Zusammenfassend erscheint in der weiteren Entwicklung der Eingriffe am ovalen Fenster, wenn man die erheblichen Bedenken allgemeiner Art gegen Kunststoffe außer Acht läßt, die Berücksichtigung folgender Punkte wichtig. Der Ersatzsteigbügel sollte aus einem Stück sein, um die Bildung von unerwünschten pseudogelenkigen Verbindungen zwischen Fensterdeckung einerseits und dem Verbindungsstück zum langen Fortsatz andererseits zu vermeiden. Die Ersatzfußplatte sollte der normalen in Ausdehnung, Form und Konsistenz möglichst nahekommen, um Konterbewegungen der Perilymphe zu vermeiden. Weiterhin muß die neue elastische Verbindung im Gebiet des Ringbands gewährleistet sein und das Gewicht des Ersatzstapes nicht mehr als 3 mg betragen, da sonst die Relationen zwischen dem zu bewegenden Gewicht und der aufgewandten Kraft nicht mehr übereinstimmen. Schließlich sollte auch die Unterfläche der Fußplatte möglichst der physiologischen Form angepaßt sein.

Aus vorgenannten Überlegungen bietet sich die Bildung eines Ersatzstapes aus Knochen als nächstliegende Möglichkeit an. M. Portmann hat 1959 bereits eine Methode zur Bildung eines knöchernen Stapes aus der Gehörgangswand angegeben, aber diese später wieder verlassen. Zöllner referierte auf dem diesjährigen internationalen Kongreß in Paris ebenfalls über die Interposition mit kleinen Knochenstückchen.

1959 hat Utech in einer Arbeit über die Verwendungsmöglichkeit des Knorpels als Teilersatzstücke neben noch vorhandenen Teilen des Steigbügels referiert. In dieser Veröffentlichung wird auch eine Methode angegeben, in der nach Entfernung der Crurae ein Stück Knorpel zwischen langem Fortsatz und der in der Mitte gefensterten Fußplatte eingefügt wird. 1961 wurde von Niedermeier über die Verwendung von Ohrknorpel zur Unterfütterung der Sklera bei größeren Defekten berichtet. Diese Methode hat sich in der Ophthalmologie ausgezeichnet bewährt und ist dort weitestgehend eingeführt.

Angeregt durch die Verwendung in der plastischen Chirurgie wurde hier

Abb 13 Operationsfoto des Steigbügels aus Knorpel in der fertigen Position

seit 1959 ein Ersatzsteigbügel aus Knorpel bei entsprechender Indikation verwendet Bevor die Einführung von Knorpel als Stapesersatz in Frage kam, erschien die Klärung folgender Fragen wichtig

1 Ist die Erhaltung des eingesetzten Knorpelstücks in seiner ursprünglichen und gewünschten Form möglich?

2 Genügt die Festigkeit, um der Funktion des normalen Stapes möglichst nahe zu kommen?

3 Ist eine geeignete Formung möglich?

4 Welche Knorpelart soll verwendet werden?

5 Soll das Perichondrium erhalten bleiben oder soll skelettiert werden?

6 Soll das ovale Fenster vorher mit Bindegewebe oder Venenwand verschlossen werden, um den Knorpelstapes darauf zu lagern, oder soll die Unterfläche des neuen Steigbügels unmittelbar auf die Perilymphe einwirken?

Zu 1 Als Autotransplantat wird Septum und Ohrknorpel von den bekannten Autoren Schuchardt, Güntert, Obweger, New, Erich, Peer und anderen als elastischer Knorpel am anspruchslosesten geschildert Nach Peer war er nach sechs Jahren noch in seiner ursprünglichen Form erhalten Über diese Knorpelart hat man bis jetzt auch die größte Erfahrung sammeln können

Zu 2 Die mechanische Belastung ist außerordentlich gering In dieser kleinen Ausdehnung ist das Transplantat als feste Masse anzusehen

Zu 3 Die gute Möglichkeit zur Formung ist als der größte Vorteil des Knorpels anzusehen Auch in kleinsten Dimensionen ist er gut zu schneiden

Zu 4 Wenn auch in den einschlägigen Arbeiten unterschiedliche Mei

nungen auftreten, so kommt doch zum Ausdruck, daß bei dem geringen Umfang des Materials dem Autotransplantat der Vorzug zu geben ist. Hetero- und Homoiotransplantate von Swinney, Wardill, Firestone, Peer, Brown, Lamont, Pierce und O'Connor in Arbeiten besprochen, mussen vom umgebenden Gewebe eingeschlossen werden und werden spater meist durch Bindegewebe weitgehendst ersetzt.

Zu 5. Da in dem Bezirk des ovalen Fensters eine restlose Umschließung des Knorpeltransplantats auch nach Anlegen der vorher mobilisierten Paukenhohlenschleimhaut mit Gewebe nicht sofort moglich ist und zur Erhaltung der Beweglichkeit auch nicht erwunscht wird, wird auf der dem Facialiskanal abgewandten Seite das Perichondrium in der oberen Halfte erhalten. Die Ernahrung des elastischen Knorpels ist nach Peer, Schuchardt und anderen weitgehendst vom Perichondrium abhangig. Andererseits soll nicht zu viel Perichondrium am gesamten Knorpelstapes erhalten bleiben, um narbige Verwachsungen zu vermeiden, die die unbedingt notwendige Beweglichkeit einschranken konnten.

Zu 6. Da auch die Unterflache des neuen Knorpelstapes mit der Frase unter dem Operationsmikroskop der physiologischen Form moglichst nachgebildet werden soll, ist es wunschenswert, diese unmittelbar auf die Perilymphe einwirken zu lassen. Die elastische Verbindung im Bezirk des Ringbands kommt durch Anlegen der Paukenhohlenschleimhaut zustande.

Nachdem also grundsatzlich die Moglichkeit zur Autotransplantation von Septum- oder Ohrknorpel gegeben schien, wurde zunachst nach folgender Technik vorgegangen: Nach Entfernung der gesamten Fußplatte sofortiges Abdecken des eroffneten ovalen Fensters mit Bindegewebe, um Einsickern von Blut und Abfluß von Perilymphe zu verhindern. Anschließend am Helix Exstirpation des Knorpels mit Stanze. Nachpraparieren und Einsetzen, wobei das Perichondrium an den langen Fortsatz angelegt wird. Der notwendige Raum zwischen der knorpeligen Fußplatte einerseits und dem außeren Rand des ovalen Fensters andererseits wird mit der vorher abpraparierten Paukenhohlenschleimhaut uberdeckt und abgedichtet zur Vermeidung einer Fistelbildung.

Als Form wurde ein Dreieck gewahlt, dessen Spitze eine Eindellung hat, um den Gelenkfortsatz des langen Amboßschenkels aufzunehmen. Diese Form ergibt sich schon bei Anwendung der Stanze Nr. 1. Da aber die Unterflache dieses Dreiecks ein Rechteck ist, dessen Länge zwar durch die Stanze, die ja nur in einer Ebene schneiden kann, bestimmt wurde, dessen Breite aber der Dicke des Ohrknorpels entspricht, ware dieses Stuck zur sofortigen Implantation ungeeignet. Es muß also mit der Stanze Nr. 2 von oben nach unten die passende ovale Form hergestellt werden. Beide Stanzen mussen in verschiedensten Großen vorhanden sein, um den unterschiedlichen Abmessungen des ovalen Fensters gerecht zu werden.

Bei dieser Technik bestand der Knorpelstapes aus einem massiven Stuck in oben beschriebener Form. Die Ergebnisse in prozentualer Aufteilung waren folgende: in 70% der Falle Anstieg der Luftleitungslinie bis auf 5 db an die

Innenohrleistung, 20% bis auf ca. 5–15 db, 8% zwischen 15 und 25 db, 1% ohne Erfolg und 1% Innenohrschaden.

Im letzten Halbjahr konnten die Erfolge bis 5 db auf ca. 90% gesteigert werden, indem die Technik in folgender Form geändert wurde. Anstelle des Ohrknorpels wurde autoplastischer Septumknorpel verwendet. Septumknorpel ist wesentlich härter als Ohrknorpel und kann daher ohne Verlust an Stabilität noch besser geformt werden. Infolgedessen besteht die Möglichkeit mit Hilfe der angegebenen Stanzen die äußere Form schnell zu gewinnen. Mit einer Luftturbinenfräse wird aus dieser Form ein Stapes modelliert, der dem normalen sehr ähnlich ist und ein Gewicht von ca. 3 mg hat.

Alle Knorpelimplantate heilten primär ohne Nebenerscheinungen ein. Der endgültige Hörgewinn wurde innerhalb von 2 bis 3 Wochen erreicht. Ein späteres Absinken des in gleicher Höhe liegenden Ton- und Sprachgehörs infolge einer Reankylose oder anderer narbiger Refixationen trat nicht auf. Degenerative Veränderungen des Knorpels wurden nicht beobachtet. Insgesamt wurden ca. 70 Fälle operiert.

ZUSAMMENFASSUNG

Nach kurzen Ausführungen über die verschiedenen Operationsmethoden werden die physiologischen Reaktionen des Steigbügels den Bewegungen gegenübergestellt, die nach den z. Zt. gebräuchlichen Eingriffen auftreten. In Kenntnis der noch bestehenden Verbesserungsmöglichkeiten wurde eine neue Technik entwickelt, bei der als Stapesersatz autoplastischer elastischer Knorpel von Ohr oder Septum verwendet wird.

Zunächst wurde ein kompakter Ersatzsteigbügel aus dem Helix verwendet, wobei ca. 70% der Fälle bis auf 5 db an die Knochenleitung herankamen. Neuerdings erreichten nach Vervollkommnung der Technik und Verwendung des härteren Septumknorpels ca. 90% die 5 db-Linie. Die sprachaudiometrischen Werte lagen auf der gleichen Höhe.

Nach den bisherigen Erfahrungen erscheint der Beweis für die Eignung von elastischem Knorpel als Ersatzstapes erbracht. Es kam in keinem Fall zu Nekrosen, oder andern unerwünschten Reaktionen, die zu entzündlichen Prozessen oder Behinderung der schnellen Einheilung des Knorpels führten.

SUMMARY

After a short explanation of the different operational methods the physiologic reactions of the stapes are compared with the movements existing after the usual techniques. In view of the still existing possibilities of correction a new technique was developed, using an elastic ear or septum cartilage. At first a compact stapes was made with cartilage from the helix. In 70% of all cases the hearing gain came to 5 db in bone conduction. After perfecting the technique and using cartilage from the septum the bone conduction gain reached 5 db in 90% of all cases. Sound and speech audiometry was on the same level. The new cartilaginous stapes healed in directly without any reactions or necrosis.

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SUMMARY

After a short explanation of the different operational methods the physiologic reactions of the stapes are compared with the movements existing after the usual techniques In view of the still existing possibilities of correction a new technique was developed, using an elastic ear or septum cartilage At first a compact stapes was made with cartilage from the helix In 70% of all cases the hearing gain came to 5 db in bone conduction After perfecting the technique and using cartilage from the septum, the bone conduction gain reached 5 db in 90% of all cases Sound and speech audiometry was on the same level The new cartilaginous stapes healed in directly without any reactions or necrosis

OPERATIVELY TREATED CASE OF MORBUS OTOLITHICUS (OTOLITH EXTRACTION AFTER TEMPORARY STAPEDIOLYSIS)

M. Bergstedt and G. Herberts
Umeå, Sweden

From the Department of Otolaryngology (Head: Prof. G. Herberts), Royal Medical School, Umeå

In connection with a severe case of Ménière's disease, in which the pathological process, to judge from the pre-operative vestibular examination, was confined to the otoliths, an operation involving extirpation of the otoliths through the oval window after temporary stapediolysis was carried out. The significance of careful vestibular examination in order to localise the pathological process is stressed. Alcohol positional tests are suggested as a way of complementing (intensified positional test) the examination. The possibility that improved diagnostics combined with further developments in operative technique would lead to better results is pointed out.

Even in Ménière's well known description of the affection that bears his name one finds already the essential criteria of diagnosis: tinnitus, reduced powers of hearing and severe vertigo. This is nowadays qualified to the extent that the deafness must be basically of neural type and nystagmus should accompany the vertigo attacks. Should any of these criteria be lacking, the diagnosis of Ménière's disease ought not to be made. Clinical experience shows the disease to be very common. It affects men and women equally and is most common between 30 and 40 years of age. Bilateral Ménière's disease occurs in about 10% of the cases, the second ear usually being affected a few months after the first (Schuknecht 1960). This situation—that the disease is so often monolateral—has naturally encouraged resort to active surgical therapy. In severe cases with repeated periods of vertigo with vomiting, difficulties over balance, tinnitus and varying degrees of deafness, the patient's disease often reaches such a pitch that active surgical therapy is indicated.

Among the current tried methods of surgical treatment of Ménière's disease can be named:

1. Section of nervus vestibularis.
2. Partial labyrinth destruction after Arslan (ultrasonic).
3. Partial labyrinth destruction after Frenckner, Herberts, Rydmark and others.
4. Labyrinth destruction according to Cawthorne, Lempert and others.

Of the purely operative procedures the method according to Cawthorne is probably the one in most common use. Total labyrinth destruction produces

definitive results After a period of post operative vertigo of greater or lesser severity accompanied by nystagmus towards the healthy ear there usually follows a quick recovery without attacks of vertigo In more severe cases of Meniere s disease where there have been longer periods of vertigo and hearing is considerably reduced the post operative vertigo is even so not very pronounced The disease of the affected ear has so to speak already achieved a partial destruction of the labyrinth on that side before the operation However for reasons not yet clear the tinnitus may remain after the operation though it usually changes its character and is less troublesome than before Disturbances to balance function of a slight degree in situations making increased demands on balancing ability can be found after the operation especially with older patients Younger ones usually achieve a functional adaptation with greater ease Frenckner s method involves an attempt to spare the cochlear portion of the labyrinth The remaining methods given above have in common the treatment of the disease *without* opening the labyrinth in order to leave what hearing there is on the operated side as far as may be possible

All these methods however involve relatively large incisions and every opportunity for simplification of procedure should be taken The current operational method for endaural exploration of the middle ear has great advantages both because it is simple and because it gives direct access to the inner ear and the membranous labyrinth The post operational course is also easier after this approach Cawthorne has introduced an endaural method (membranous labyrinthectomy via the oval window) as follows After exploration of the middle ear the stapes is displaced and direct communication to the perilymphatic space achieved Cawthorne then extirpates the otoliths and subsequently replaces the stapes in the window and returns the drum membrane to its position

An incision of this type to achieve a labyrinth destruction in the treatment of Meniere s disease also gives material for vestibular studies in human beings with new aspects Careful pre and post operational analyses of the results of vestibular investigations using modern techniques may give valuable results for the diagnosis and treatment of vertiginous diseases

A case with postural vertigo and positional nystagmus is reported on below The basic affection was Meniere s disease in the left ear The main point of interest in the operation apart from the achievement of a therapeutic effect by labyrinth destruction was to ascertain the part played by the otoliths in the picture of the symptoms as a whole

Description B E G a 40 year old lumberjack (no ASU 1307/59) Earlier sickness March 1958 hospitalised at Falu lasarett for sinuit bil

Current affection In the winter of 1958 a number of severe and typical Meniere attacks lasting some hours Tinnitus and increasing deafness in left ear plus tendency to fall leftwards Before each attack came progressive deterioration of hearing in the left ear

Upon examination at the Ear Clinic at Falu lasarett (in connection with

the attacks) there was observed a direction fixed positional nystagmus to the left (at a previous examination it had been in the opposite direction) plus a tendency to fall leftwards Caloric reaction according to Hallpike showed directional preponderance to the left but normal peripheral labyrinth functioning Hearing examination with tone audiogram and balance test showed left neural deafness of 70 dB right 20–30 dB combined deafness Positive recruitment test for the upper register

Eyes and nerve status normal X ray of skull and porus normal X ray of sinus normal

The patient was totally invalided and was remitted for labyrinth destruction to the *University Hospital at Uppsala*

Status 21/7/59 ASU/General condition : good heart : normal pulm normal upper air passage normal Otoscopy normal drum membranes normal tubar function Lumbar puncture normal condition General neurological status completely negative

Cupulogram Normal post rotatory reactions right = left Positional test (nystagmography see Fig 1) showed a relatively weak type 1 positional nystagmus In supine position nystagmus to left (1 7°/sec) In right lateral position nystagmus to left in left lateral position nystagmus to right

Caloric test after Hallpike showed normal and symmetrical reactions right left (duration values) No preponderance

Tone audiogram and Bekesy audiogram showed insignificant remains of hearing in left ear (90 dB in middle register) and about 30 dB combined reduction on right (noise deafness + conductive hindrance) No explanation was obtained of patient s conductive hindrance

Summary of oto neurological examination thus showed that during attacks (12 days previously) there were observed certain neurological findings plus spontaneous and positional nystagmus (type II) and a directional preponderance of central origin in the caloric test During periods without attacks the neurological findings were negative there was weak positional nystagmus of type I and *normal caloric reaction without preponderance*

Hearing function in the left ear which was already severely reduced at the latest attack had since according to the patient completely vanished this latter was in agreement with the audiogram

Postural vertigo was a dominant symptom with the patient The otoneurological findings with objective positional nystagmus and normal ampullar reactions both during the attacks and in the remissions pointed towards *a disturbance to otolith function* as a possible cause for the release of this symptom

A morbus otolithicus in its true meaning was therefore considered to have arisen whereupon an incision through the oval window with extirpation of the otoliths according to Cawthorne was planned for the left ear

The operation was performed on 25/7/59 Temporary stapes extraction with removal of the otoliths left ear Local anaesthesia (Herberts) Exploration of middle ear in the usual manner normal anatomical conditions

there. Joint between stapes and long projection of incus was divided, after which ligamentum annularae in the forward half of the flat part of the stapes was divided with a sharp instrument and the stapes itself was luxated intact from the window, still held fast by the sinew. Inspection of the vestibulum at great magnification revealed that the otoliths were not their usual whitish colour but appeared to be covered by a reddish grey, jelly-like substance. During an attempt to remove this substance with a fine suction tube the normal chalk-white colour of the otoliths was glimpsed before they too were sucked away. Only the empty bony walls then remained (the cavity was thoroughly inspected). The stapes was replaced and articulation was adapted so that good contact was obtained. Ext. meatus tamponade, one suture.

Post operative course. For a few days, nystagmus to the left and pronounced vertigo troubles. After one week, nystagmus to the right and subjective remission of trouble. Hearing function was subjectively improved initially and the patient lateralized to the operated ear. A good week later this subjective improvement was reversed and the patient lateralized to the healthy side. Audiogram two weeks after operation showed no definite signs of air conduction in the left ear. Course of healing was complication free.

The vestibular findings after the operation can be seen in the diagram (see Fig. 1). Sixteen days after the operation there was discovered in the nystagmogram a relatively weak destruction nystagmus to the right. In supine position, weak nystagmus to right (2.4°/sec). In right lateral position, weak nystagmus to right. In left lateral position, no nystagmus.

Caloric test showed canal paresis on the left side for cold and warm water. With water temperature of +5°C the reaction from the left ear had a maximum intensity of nystagmus of 5.3°/sec, or an increase of 5.3–2.4 = 2.9°/sec.

Two days later, nystagmus in the supine position was less marked, pointing

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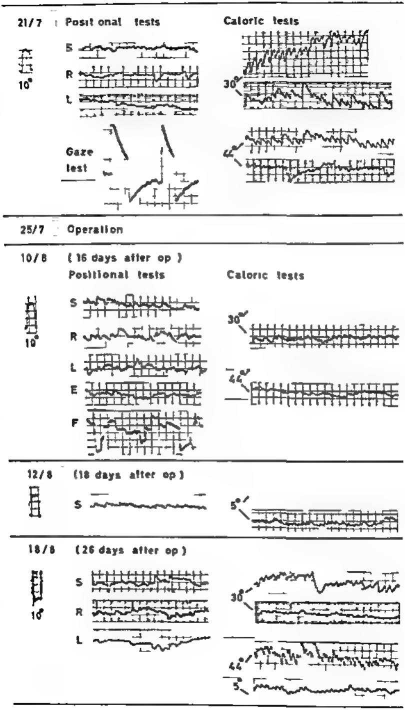
Fig. 1. Nystagmogram from the case with Ménière's disease in the left ear and typical "morbus otolithicus". Recordings of horizontal eye movements made during positional and caloric tests before and 16, 18 and 26 days after operation (otolith extraction after temporary stapediolysis). A deflection upwards of the trace corresponds to a right horizontal deflection of the eye and a deflection downwards to a left horizontal deflection of the eye.

Before operation the positional test shows weak nystagmus to the left in supine position (S) and right lateral (R) but to the right in left lateral position (L). The gaze test (with 30° deviation of the visual axis to right and left) shows no nystagmus. The caloric test according to Hallpike with water of 30 and 44°C is normal (in the figure maximum intensity in order from above: 30°C right ear, 30°C left ear, 44°C right ear and 44°C left ear).

Sixteen days after operation. Nystagmus to right in supine and in right lateral position, and no nystagmus in left lateral position. Sitting position (L), nystagmus to right and in head hanging back position (B) only irregular eye movements but no nystagmus. Irrigation of left ear shows lowered sensitivity.

Eighteen days after operation less marked nystagmus to right and caloric test with water at 5°C produced only weak increase in nystagmus intensity.

Twenty-six days after operation weak nystagmus to right in supine and right lateral position and only the slightest nystagmus to the left in left lateral position. Caloric test left ear with water at 30°C gives no reaction and water at 5°C a weak reaction.


21/7
Positional tests
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Gaze test
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Operation
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to a quick acting central compensation Calorisation with water at 5°C produced only weak increase in nystagmus intensity Examination 26 days after operation showed continued compensation There was only the slightest nystagmus to the left in the left lateral position in the supine and right lateral positions there was still weak nystagmus to the right Twenty eight days after the operation (see Fig 2) there was no definite nystagmus in the supine position On the other hand there was nystagmus of similar intensity to the left in the left lateral and to the right in the right lateral positions To make a closer study of nystagmus after the operation (cessation of labyrinth function) acute alcohol intoxication was carried out followed by positional tests of the same pattern as used with healthy subjects (cf Aschan Bergstedt Goldberg)

This alcohol test produced a clear positional alcohol nystagmus phase I (nystagmus to right in right lateral and to left in left lateral positions) In supine position on the other hand there was no definite nystagmus

Post operative cupulogram showed significantly shortened post rotational reactions (less than half of the pre operational values) but no definite lateral difference (left = right)

Summary of post operative vestibular findings Left ear showed a gradual reduction of caloric reaction pointing to reduced function and finally complete inactivity Spontaneous and positional nystagmus tests showed an active phase for several days post operatively thereafter a destruction phase and later about 1 month after operation only a remaining positional nystagmus type I but no certain directional preponderance The alcohol test confirmed the result of the positional test which gave reinforced symmetric reactions in the lateral positions and none in the supine position

Cochlear function showed an initial post operative improvement but later—together with the symptoms of labyrinth destruction—complete inactivity

The patient s subjective troubles disappeared rapidly (*some days*) *after* the operation He considered these initial symptoms to be considerably less painful than those of the preoperative attacks

Follow up About 6 months later the patient informed us that he had been fit for work after the operation and was subjectively free from symptoms

DISCUSSION

It is of interest to try to establish whether the preoperative diagnosis in this case—morbus otolithicus—can be verified by the findings of the operation and the post operative vestibular examinations

The significance of the gelatinous covering round the otoliths noticed during the operation is difficult to judge The surgeon (Herberts) who has had the opportunity of studying the appearance of the otoliths at high magnification both during operations with Cawthorne and in a number of other operations has neither before nor since seen anything similar to it It would

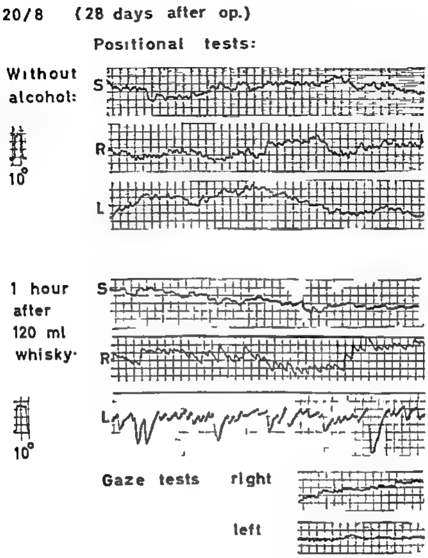

Fig. 2. Nystagmogram. Continuation from Fig. 1.

Twenty eight days after operation without alcohol: no definite nystagmus in supine position but weak positional nystagmus of similar intensity to the left in left lateral and to the right in right lateral position.

About 1 hour after alcohol no nystagmus in supine position but typical positional alcohol nystagmus of similar intensity (but a little different frequency) in right and left lateral positions. Gaze test: usual (but a little weak) gaze nystagmus after alcohol.

naturally have been of great value if a pathologico-anatomical diagnosis could have been carried out

During the initial post-operative stages the patient had subjective and objective symptoms of labyrinth irritation in the operated ear (ampullary portion?) The later rapid appearance of compensation with symmetric positional nystagmus without directional preponderance in spite of cessation of ampullary reaction points to the conclusion that the patient's many and intense pre-operative attacks had already laid the foundations of compensation (with the otoliths already "knocked out" before operation) This would be consistent with an affection pre-operatively localised on the otoliths in the left ear

The positional alcohol test which can be considered an intensified form of positional test (Bergstedt) usually gives an intensified picture of any asymmetry which may possibly exist at the normal positional test Its value in assessing vestibular function where there are cases of labyrinth incision ought in our opinion to be more closely considered

Earlier experience teaches that every incision which is accompanied by total labyrinth destruction can give good results in cases of Ménière The endaural method with temporary stapediolysis would seem however to be the one preferred in certain cases This is certainly true in those cases where the aim is to excise a morbid change localised around the otoliths Any possibility of saving the labyrinth in general through improved operative technique ought to be tried (membranous labyrinthotomy with careful extraction of the otoliths)

ZUSAMMENFASSUNG

Eine Operation mit Exstirpation der Otholithen durch das ovale Fenster wurde nach zeitweiliger Stapediolyse durchgeführt Bei einem schweren Fall von Ménière scher Krankheit wo sich der pathologische Prozess nach dem Ergebnis einer präoperativen Vestibularisuntersuchung auf die Otholithen beschränkte Die Bedeutung sorgfältiger Vestibularisuntersuchung zur Lokalisierung des pathologischen Prozesses wird hervorgehoben Ortungsteste mit Alkohol (intensivierter Ortungstest) werden zur Ergänzung der Untersuchung vorgeschlagen Es wird auf die Möglichkeit hingewiesen dass verbesserte diagnostische Mittel verbunden mit weiterer Entwicklung der Operationstechnik zu besseren Resultaten führen können

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Dept of Otolaryngology Royal Medical School Umeå

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INSTRUMENTAL PERFORATION OF THE ESOPHAGUS

ÅKE LENÉR and OLLE DAHLBÄCK
Lund, Sweden

From the Departments of Ear, Nose and Throat (Head: Prof. Hjalmar Koch, M.D.) and Thoracic Surgery (Head: Olle Dahlbäck, M.D.), University Hospital, Lund

A report is given of 26 instrumental perforations of the esophagus from January 1950 to April 1961. Nineteen of the perforations occurred at the University Hospital, Lund, or at Malmö during 3964 esophagoscopies, representing 0.51%, and four at other hospitals. The remaining three occurred during instrumental manipulation other than esophagoscopy. Eleven patients were operated upon and 15 were given medical treatment. There were three deaths among the operated cases and five deaths among the cases treated medically. Some aspects of treatment, as well as diagnosis, level and frequency of perforation are discussed.

Material

The present material includes all cases of instrumental esophageal perforation treated at the University Hospital, Lund or at Malmö from January 1950 to April 1961. The series consists of 26 patients (13 males and 13 females), aged 4 to 81 years (average 56 years).

Twenty two of these perforations had occurred in Lund or Malmö: 19 during esophagoscopy and operations performed through the esophagoscope and one during passage of a catheter, one on passage of a dosimeter and one during dilatation without esophagoscopy.

These 19 cases represented a frequency of 0.51% of the 3964 hypopharyngo-esophagoscopies performed during the period covered by the investigation. The remaining 4 cases had occurred in other hospitals and had been referred to our departments for treatment.

Diagnoses

It is clear from Table 1 that perforation was most common among patients with cancer and occurred in 6 cases, which, in view of the great risk of perforation in such patients and the fact that biopsy was always done, must be regarded as a low figure. In 4 cases the patients had diaphragmatic [illegible] which exemplifies the risk involved in endoscopy if the anatomy of [illegible] third of the esophagus is severely deranged and difficult to judge [illegible] tients were grouped under the heading of chemical burns, on [illegible] heading of esophageal stricture. It may seem artificial to mal[illegible] between these two groups, but only those patients known w[illegible] have swallowed some caustic fluid were assigned to the f[illegible]

TABLE 1

Diagnoses	No. of cases
Cancer	6
Hernia diaphragmatica	4
Strictura esophagi	3
Combustio alkali	3
Dysphagia	3
Corpus alienum	2
Achalasia cardiae	1
Diverticulum esophagi	1
Syndr. Plummer–Vinson	1
Ulcus ventriculi	1
Retentio ventriculi	1

latter group consisted of cases of obscure origin and included one patient with a radiation stricture. It is, of course, probable that this group also included strictures due to caustic burns, but inquiry into the personal history of these patients failed to reveal any support for such an assumption. The patients with Plummer–Vinson syndrome represented a separate clinical entity, and were allotted to a special group.

Instrumental Examination (Operations)

Of the 26 perforations, 12 occurred during esophagoscopy only, 6 during esophagoscopy with dilatation, 4 during esophagoscopy with removal of a biopsy specimen, 1 during extraction of a foreign body, and 3 during instrumentation without esophagoscopy (Table 2).

Level of Perforation

It is clear from Table 3, which also includes the number of deaths, that the perforation had occurred in the upper third of the esophagus in 9 of the

TABLE 2

Instrument	No. of cases
Esophagoscopy only	12
Esophagoscopy with dilatation	6
Esophagoscopy with biopsy	4
Esophagoscopy with foreign body	1
Dilatation only	1
Insertion of dosimeter	1
Insertion of stomach tube	1

TABLE 3 *Level of perforation*

Early operation		Late operation		Medically treated			
Perf	Dead	Perf	Dead	Perf	Dead	Total	Dead
1	1	5	1	3	0	9	2
1	1	0	0	2	1	3	2
3	0	1	0	10	4	14	4

patients in the middle third in 3 and in the lower third in 14 This distribution of the lesions differs from that reported in the literature and will be commented upon in a later section

Treatment

Eleven patients were operated upon and 15 received medical treatment (Tables 4 to 6) In 9 of the operated patients surgery was reparative with closure of the lesion in the esophagus In the remaining 2 the perforation could not be located and treatment was limited to incision and drainage The cases were divided into two groups according to the interval between perforation and operation the 5 cases operated upon within 10 hours being classified as "early" the 6 after 10 hours as "late" The choice of this interval may appear arbitrary but no appreciable infection occurred in the early group Two deaths occurred in the early group

Cases operated upon without delay seemed to have a less eventful convalescence e g case no 1 (Table 4)

TABLE 4 *Early operated cases (within 10 hours)*

Case	Age	Disease	Interval in hours perf.-op	Outcome	X-ray findings
1	[illegible]	Dysphagia	4	Healed	Enth sin, contrast to pleura
2	[illegible]	Achalasia	3	Healed	Enth sin
3	51	Hernia diaphragm	3 4	Dead	Enth Ix, broadening of mediast
4	53	Hernia diaphragm	6	Dead	Broadening of med, contrast to med
5	[illegible]	Ulcus ventriculi	[illegible]	Healed	Collapse right lung, effusion

A woman aged 71 was admitted to hospital with a history of chronic dysphagia. X-ray examination showed a narrowing of the lower part of the esophagus. Esophagoscopy on two occasions showed nothing pathological in the mucosa but 35 cm from the teeth there was a slight narrowing from the outside. The patient was therefore admitted to one of our clinics and esophagoscopy again performed to show similar findings but X-ray showed a left-sided pneumothorax, with barium contrast leaking into the pleural space. A thoracotomy was performed within 4.5 hours and a perforation of 1 cm was sutured just proximal to the cardia. No stricture or tumour was to be found and the dilated heart was thought to have caused the narrowing. A drain was inserted and maintained with continuous suction. Convalescence was uncomplicated and since leaving hospital, the case has been reviewed several times, when the findings were quite normal.

One patient (No. 4) died from respiratory failure 4 days after operation with closure of the esophageal lesion as well as radical treatment of the hiatus hernia. Post-mortem examination revealed nothing of interest at the operative site but massive bilateral atelectasis. Death was thus due to inadequate treatment of respiration and could probably have been warded off by early tracheostomy. In addition the patient was obese and the chances of respiratory complications were therefore considerable from the very beginning.

TABLE 5. *Late operated cases (more than 10 hours)*

Case	*Age*	*Disease*	*Interval perf.-op.*	*Outcome*	*X-ray findings*
1	63	Hernia diaphr.	24 hours	Healed	Broadening of med. + abscess
2	4	Corpus alien.	48 hours	Healed	Mediast. and subcut. emphys.
3	[illegible]	Combustio alk.	10 days	Healed	Mediastinal abscess
4	70	Plummer-Vinson	26 hours	Healed	Mediast. and subcut. emphys. + pyopneumothorax
5	51	Cancer hypophar.	14 days	Dead	Broadening of med. + paraesophageal abscess
6	63	Corpus alien.	15 hours	Healed	

In the other group, i.e. patients not operated upon until at least 15 hours after the accident, one patient died (Table 5). He had hypopharyngeal cancer for which he had received radiotherapy. On insertion of the dosimeter the esophagus was injured. The clinical diagnosis was verified roentgenologically. But operation was not done until 14 days later, when a large abscess was drained. The inflammation of the tissues was too severe to permit location or repair of the lesion. The abscess recurred with subsequent bleeding and the patient died 2 months after the perforation. The subclavian artery had become eroded with massive bleeding as a result.

The hazardous and protracted type of convalescence if operation is delayed is illustrated by case No. 4.

This was a woman aged 70 with a history of dysphagia of 15–20 years duration who had been treated several times for anemia. She had a stricture of the Plummer Vinson type which had been dilated once. About two months after this dilatation she was again admitted to hospital and at esophagoscopy a perforation was done just proximal to the stricture. She then complained of severe pain in the chest and developed a subcutaneous emphysema over the neck. Some hours later, X-ray examination showed a broadening of the mediastinum and atelectasis of the left lung. Her temperature rose and she complained of pain in the upper chest and abdomen. Thirty six hours after the perforation the patient was admitted to our clinic. She was in rather poor condition, temperature 38.6 C. with a mediastinal and subcutaneous emphysema and signs of pleural effusion on the right side. The right lung showed atelectasis in the basal parts. She was operated upon immediately and the perforation sutured. The right pleural sac contained large amounts of pus. Drainage tubes were inserted and continuous suction maintained. Afterwards the patient developed respiratory insufficiency, necessitating tracheostomy and respirator treatment. Large doses of penicillin and chloromycetin were given together with streptomycin. Her recovery was slow, uncertain and the patient could not be discharged for a further two months.

TABLE 6. *Medically treated cases*

Case	Age	Disease	Outcome	X-ray findings
1	54	Dysphagia	Healed	Mediastinal and subcutaneous emphys.
2	43	Combustio alk.	Healed	Mediastinal and subcutaneous emphys.
3	81	Dysphagia	Healed	Broadening of mediastinum + pnth sin.
4	51	Cancer esoph.	Dead	Fistula to mediast. + paralytic ileus
5	61	Status post ca.	Dead	Pyopneumothorax sin.
6	67	Hernia diaphr.	Healed	Mediastinal emphysema + pleuritis dx.
7	41	Combustio alk.	Healed	Broadening of mediastinum with overflow of contrast
8	[illegible]	Retent. ventr.	Dead	Mediastinal abscess. pnth bil.
9	70	Divert. esoph.	Healed	
10	59	Cancer esoph.	Healed	
11	81	Divert. esoph.	Healed	Broadening of mediast. pleuritis dx.
12	10	Combustio alk.	Healed	Contrast to mediastinum
13	48	Combustio alk.	Healed	Contrast to mediastinum
14	73	Cancer esoph.	Dead	
15	72	Cancer esoph.	Dead	

In the conservatively treated group (Table 6) therapy consisted of the administration of antibiotics and when necessary thoracocentesis. The diet was restricted to liquid food given by stomach tube.

The chemical burns occupy a special position. In the acute stage the injury is probably not limited to the mucosa but also deeper with involvement of peri-esophageal tissues. Later after cicatrization and the development of a stricture the mediastinum is presumably more or less obliterated. The loose structures otherwise favouring spread of the infection no longer exist. Perforation due to the ingestion of caustic liquids may therefore be regarded as

less serious (cases Nos 2, 7, 12, 13) This assumption is supported by the course in case 13, in which mediastinal fistula was not discovered until 3 weeks after endoscopy and was roentgenologically demonstrable up to 3 years afterwards

TABLE 7

Cases treated surgically	11	Deaths	3
Cases treated medically	15	Deaths	5
		Total	8

Summarizing, of 26 instrumental perforations of the esophagus, 11 were treated surgically and 15 conservatively (Table 7) There were eight deaths, three in the group treated surgically and five in the group treated conservatively *The perforations were located in the upper third of the esophagus in* nine cases, in the middle third in four, and in the lower third in 14 The series was too small to warrant any conclusions from a statistical point of view The majority of the perforations occurred during esophagoscopy only, i e without further intervention The perforations represent a frequency of 0 51 % of a total of 3964 examinations

DISCUSSION

The use of the esophagoscope has increased considerably in recent years Thus, Jemerin reported an increase of 100% at Mount Sinai Hospital during the years 1937–1946 compared with the previous 10 year period A similar *increase has also been reported from the Mayo Clinic For comparison it* might be mentioned that at the E N T Department, University Hospital, Lund, esophagoscopy was performed 150–200 times during the first years of the 1950s as against more than 400 in 1960 This wider use of the esophagoscope is, of course, accompanied by a larger risk of instrumental perforations and thereby increases the importance of adequate treatment of these lesions

In the present series the distribution of the perforations according to level differed somewhat from that usually reported in the literature The cervical perforations seem to be the most common and the passage of the oesophagoscope past the cricopharyngeus appears to be the most difficult part of esophagoscopy Jackson characterized the cricopharyngeal constriction as Bab el Mandeb or the gate of tears obviously for the operator In the present series, however, most of the perforations occurred in the lower third of the esophagus with its sagitally and horizontally deviating course just above the cardia In another Swedish series from the Sabbatsberg Hospital Rietz & Werner (1959) also found the perforations to be most common in the distal third The frequency of perforation agrees well with what is given in the literature Bell, Beskin & Starkey (1956) found a frequency of 0 71 %

As a rule perforation of the esophagus offers no diagnostic difficulties

The time relationship between esophagoscopy and the development of the frequently dramatic clinical picture is obvious and thereby also the causal relationship

In most cases the patient experiences pain of varying severity In the beginning the patients sometimes report only slight discomfort but more frequently severe substernal pain which sometimes occurs during esophagoscopy and sometimes not until some hours afterwards The clinical picture often becomes dramatic with symptoms of shock dyspnea and cyanosis and marked dysphagia Subcutaneous emphysema can often be palpated over the neck and chest especially if the perforation is situated in the cervical part of the esophagus The body temperature usually rises and sometimes considerably after initial chills

Laboratory studies appear to be of less interest apart from a frequent rise in the number of white blood cells a finding sometimes missing in the most dramatic cases with shock As a rule the E S R increases rapidly to high levels

Esophageal injury is confirmed by roentgen examination which can reveal any increase in the breadth of the mediastinum with emphysema and—if the mediastinal pleura is damaged—varying degrees of pneumothorax and effusion In most of the present cases roentgen examination gave conclusive evidence but it should be stressed that in the early stage the clinical picture is as a rule more reliable Examination with a barium swallow can however give a quick and exact pictre of the perforation

As far as treatment is concerned esophageal perforation should be regarded in the same way as a perforation of the alimentary tract The most logical treatment is thus rapid surgical intervention with primary closure of the lesion in the esophagus either through a cervical incision if the perforation is located high up the esophagus or via thoracotomy Most authors agree that the operation should preferably be performed within 6 hours of the accident or before infection has had time to develop Adequate drainage is also important because most of the bacteria are anaerobic Antibiotic therapy alone is not sufficient except perhaps for so called pinhole perforations caused by a small thin foreign body and producing only very mild symptoms But even in such cases operation is indicated unless all symptoms and signs of perforation soon disappear If the operation is not performed until later i e when infection has developed the further course is often protracted and complications often life threatening are common Surgical repair of the esophagus should be extended to include the establishment of a gastric fistula to permit effective nutrition and to spare the esophagus for a sufficiently long period

The risks of esophagoscopy and gastroscopy are thus obvious These examinations should therefore be performed by well trained specialists Intubation anesthesia with relaxation of the muscles diminishes the risk of perforation and should therefore always be used Anesthesia also provides better working conditions for the operator it facilitates evaluation of the findings and reduces the time necessary for examination and operation

ZUSAMMENFASSUNG

Es wird ein Bericht über 26 instrumentelle Perforationen des Ösophagus vom Januar 1950 bis April 1961 gegeben 19 Perforationen kamen an der Universitäts klinik Lund-Malmö vor, bei 3964 Ösophagoskopien, entsprechend 0,51 ‰, während 4 sich an anderen Kliniken ereigneten Die übrigen 3 Perforationen kamen bei anderen instrumentellen Manipulationen vor 11 Patienten wurden operativ und 15 wurden konservativ behandelt Unter den Operierten kam es zu 3 Todesfällen und zu 5 Todesfällen bei den konservativ Behandelten. Diagnose, Niveau und Häufigkeit der Perforation sowie verschiedene Gesichtspunkte zur Behandlung werden besprochen

Eleven patients in this series have kindly been placed at our disposal by the Department of Thoracic Surgery, Malmö General Hospital, to which we are most obliged

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E N T Dept, University Hospital Lund

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MASKING AND BONE CONDUCTION

A case report

C. P. Goetzinger, G. O. Proud and J. F. Embrey,
Kansas City, Kansas, U.S.A.

Department of Otolaryngology, Kansas University School of Medicine, Kansas City 12

The possibility of pseudo thresholds and pseudo discrimination scores in an ear with almost a total perceptive loss of hearing is a constant danger, particularly when the contralateral ear is conductively impaired and manifests hypersensitive bone conduction.

By applying basic principles of masking and bone conduction the pseudo characteristics of the severely perceptively deafened ear could be demonstrated. The importance of applying masking when less than a 40 db difference exists between ears by air conduction, especially when the levels at which measurements are conducted exceed 55–60 db, is brought into focus.

The pros and cons of masking and bone conduction have been extensively discussed in the literature. That many atypical cases are observed is unquestioned. However, it is our impression that atypicalness at times can be attributed to a lack of application of the basic principles of masking and bone conduction. The present case is reported, therefore, because it is believed to illustrate atypicalness and the possibility of an incorrect diagnosis if certain principles pertaining to masking, bone conduction and cross hearing had not been given proper consideration.

Fig. 1 A shows the pure tone air, bone and SAL test results of an 18 year old male patient recently seen in the ENT and Hearing Clinics. The lettered curves designate bone conduction and the numbered curves air conduction under the various test conditions as explained in the legend. All measurements were verified by repeated tests during a two day visit to the clinics.

As will be observed in Fig. 1 A there is relatively close agreement between the SAL bone conduction and the conventional bone test from the mastoid for the right ear when the left ear is not masked (curves A and B respectively) with the exception of 4000 cps where better sensitivity is indicated by the former. Conventional bone conduction of the left ear with 105 db of white noise on the right ear is illustrated by curve C. The air conduction audiogram of the right ear is shown by curve 1. Curves 2, 3 and 4 represent respectively air conduction thresholds of the left ear in the absence of masking of the right ear, with 85 db of masking on the right ear and finally with 105 db of masking on the right ear. (Masking in db throughout this paper refers to the overall level of the white noise relative to 0.0002 microbar.)

Under Speech Data 1 C is listed a battery of speech reception thresholds and discrimination test scores by both air and bone conduction with and

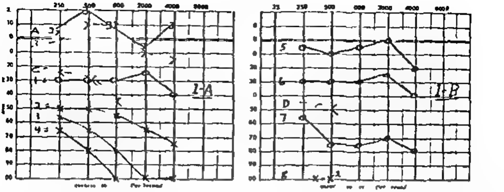

FIG. 1. A. SAL of R.E. B. Bone of R.E. (no noise on L.E.) C. Bone of L.E. (noise 105 db on R.E.) D. Bone of L.E. (noise 105 db on R.E. post op.) 1. Air of R.E. (pre op.) 2. Air of L.E. (no noise on R.E.) 3. Air of L.E. (noise 85 db on R.E.) 4. Air of L.E. (noise 105 db on R.E.) 5. Air of R.E. (post op.) 6. Air of R.E. (pre op.) 7. Air of R.E. (noise 105 db on R.E. pre op.) 8. Air of L.E. with noise 10? db on R.E. Also SAL of L.E. (both post op.)

Note. The Reference level for the white noise used in the masking was 0.000? dyne/cm²

Speech Data 1 C

I. Air W-2 S/R/T
R.E. 30 db
L.E. [illegible] db (no noise R.E.)
L.E. 9? db (noise 105 R.E.)

II. Bone W-2 S/R/T
R.E. 3 db (no mask)
L.E. 1 db (no mask)
L.E. ?7 db (noise 95 db on R.E.)
L.E. 33 db (noise 105 db on R.E.)

III. SAL W-2 S/R/T
R.E. −5 db
L.E. No response

IV. Air W-22 Discrim.
R.E. 96% (no mask)
L.E. ?2% (noise 8? db on R.E.)
L.E. 44% (noise 100 db on R.E.)

V. Bone W-22 Discrim.
L.E. 36% (noise 105 db on R.E.)

without masking for the right and left ears. All of the tests referred to above were acquired pre operatively (before myringotomy).

By referring again to curves 1 and 2 of Fig. 1A as well as to I of the Speech Data 1 C it will be noted that there was good agreement between the pure tone (500, 1000, 2000) average and the W-2 speech reception thresholds for each ear when masking was not utilized. It will also be observed that the differences between ears were not very large. However, differences between ears by air conduction of as little as 25 db are routinely checked with contralateral ear masking in our clinic when there is the possibility of a false threshold contingent upon other factors. It is quite obvious from curves 3 and 4 of the left ear with the designated contralateral ear masking that such was the case here. Specifically, the obtained air conduction threshold for the left ear with the right ear unmasked (curve 2) as well as the W-2 speech reception threshold of 53 db for the left ear with the right ear unmasked were in all probability bone responses of the right ear. V. Bekesy (1960) has demonstrated that air conducted tones of about 60 db vibrate the skull and hence induce hearing by bone conduction. In the present case, as noted by curves A and B (the SAL and conventional bone of the right ear), there was excellent bone conduction for the frequency range 250–1000 inclusive, with the general

characteristics of the latter curve B being typical of a loaded middle ear (ENT examination revealed a bulging drum with middle ear effusion.) By referring to I again of Speech Data 1–C it is seen that the shift induced in the speech reception threshold of the left ear with 105 db of noise on the right ear (92 db) is in agreement with curve 4 of 1*A*.

As an initial check of discrimination by air conduction of the left ear the W-22 test was administred at a comfort level with 85 db of noise on the right ear (IV of 1–C). Comfort level for the left ear was, however, at the maximum output of our equipment for speech which is about 118 db re 0.0002 microbar. That the discrimination score of 72 % represents mostly responses of the right ear by bone conduction may be discerned from a consideration of the principles which are involved. In the first place, a white noise of 85 db SPL will shift the threshold of a normal ear about 55 db. In the case of a conductive deafness of about 30 db, the threshold shift will be approximately 25 db, or the hearing deficit minus the predetermined shift for the normal ear. This is precisely what was found for the right ear of our patient (not shown). If now, as Bekesy has shown, air conducted sounds of about 60 db induce hearing through bone conduction, it is apparent that speech at a SPL of 118 db in the left ear could be heard by bone conduction in the right ear even when this ear is masked by an 85 db white noise SPL. (For example, 118 db SPL minus (18 db SPL plus 60 db SL) equals 40 db SL (sensation level) by bone conduction evoked by air conduction of 118 db SPL (approximately). 40 db minus 25 db equals 15 db, or the approximate sensation level by bone conduction that the PB words were being heard in the right ear above the masking level of 85 db SPL noise.)

As a further check of the above the white noise masking of the right ear was increased to 100 db SPL and the discrimination test repeated for the left ear at the previously indicated comfort level of 118 db SPL. Under this condition (IV of 1–C) the discrimination score in the left ear dropped to 44 %, which is the expected direction in view of the foregoing discussion.

To examine the effects of high level noise upon the right ear (i.e., to determine whether or not linear masking was obtaining at high levels) the maximum noise output of the equipment (105 db SPL) was led to the right ear and a pure tone threshold measured under this condition. The results are shown in curve 7 of 1*B*. Clearly, the hearing level was shifted the expected amount for the range 500–4000 cps. This finding certainly tends to obviate any doubts associated with emotionality contingent upon the noise as a factor in the reduction of the discrimination from 72% to 44%. Furthermore, the speech reception thresholds by bone conduction (II of 1–C) as well as the discrimination score of 36% by bone conduction with noise 105 db on the right ear support the conclusion of bone conduction responses of the right ear.

To summarize this aspect of the study, the principles of masking as well as of bone conduction hearing by high levels of air conduction stimulation must be kept in mind to adequately assess hearing when conductive hearing loss is present as illustrated in this case.

On the second day of the visit to the clinics a myringotomy was performed on the right ear Curve 5 of 1 *B* shows the post myringotomy results Following the myringotomy of the right ear bone conduction measurements were repeated for the left ear by the conventional mastoid method with 105 db of masking on the right ear and also using the SAL test (The SAL normal shifts for our equipment are 20 40 55 55 and 50 db at frequencies 250 500 1000 2000 and 4000 respectively) Only one response could be obtained now by the conventional method namely 50 db at 500 cps or curve D of 1 *B* In addition only one response could be obtained by air conduction in the left ear namely at 100 db with noise 105 db on the right ear (curve 8 of 1 *B* i e X²) To paraphrase there was now almost a total loss of hearing in the left ear Similarly a SAL response of the left ear at 500 cps indicated perceptive hearing loss (curve 8 of 1 *B* i e X¹) It would appear from these findings that the pre myringotomy bone responses (C of 1 *A*) of the left ear *were bone responses of the right ear By considering again the actual shift in* threshold induced by the noise of 105 db SPL on the right ear before myringotomy (curves 6 and 7 of 1 *B*) one will note the threshold shifts to be 25 45 and 45 db at frequencies 250 500 and 1000 cps respectively Strikingly the bone responses of the left ear with noise 105 db SPL on the right ear (curve C of 1 *A*) were 30 40 and 55 db down from the bone conduction responses (conventional) of the right ear (curves B and C) Curve C when compared to curve A (SAL of right ear) gives essentially the same results In other words curve C probably represents responses of the right ear After myringotomy however the enhanced bone conduction which appears to accompany loading of the middle ear (Huizing 1960 Legouix & Tarab 1959) especially at frequencies 250 500 and 1000 is decreased Hence both the bone and the air conduction sensitivity diminishes as demonstrated in curves D and 8 X Unfortunately bone conduction was not re assessed at all frequencies There was a diminution of 5 db at 500 cps by conventional bone conduction

After the drop in both air and bone conduction of the left ear following myringotomy the question arose as to whether or not the Valsalva manipulation by the otologist to assist drainage in the right ear had not increased the air pressure in the left ear and hence induced the diminution of hearing in the left ear by both air and bone conduction (Huizing 1960 Legouix & Tarab 1959) To this end a myringotomy was performed on the left ear but the results were negative There were no changes in thresholds

ZUSAMMENFASSUNG

Die Möglichkeit dass sich bei fast völligem perzeptivem Gehörverlust Pseudo Schwellen und Pseudo Diskriminationswerte einstellen ist eine stetige Gefahr besonders wenn beim kontralateralen Ohr eine Leitungsschädigung mit hypersensitiver Knochenleitung vorkommt

Mit Hilfe der für Vertäubung und Knochenleitung geltenden Grundprinzipien lassen sich die Pseudo Charakterzüge des perzeptiv stark beeinträchtigten Ohres

zeigen Die Untersuchungen unterstreichen die Notwendigkeit einer Vertaubung bei einer Differenz von weniger als 40 db zwischen den Luftleitungswerten der Ohren besonders wenn die Messungen bei über 55–60 db vorgenommen werden

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Dept of Otolaryngology Kansas University School of Medicine
Kansas City 3 Kansas U S A

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CROSSED VESTIBULAR CONNECTIONS IN THE FROG[1]

N. G. Henriksson,[2] R. S. Schmidt and C. Fernandez
Chicago, Ill., U.S.A.

From the Department of Surgery (Otolaryngology), University of Chicago

The crossed vestibular root to the area statica and reticular formation was investigated in frogs by the electrophysiological method. The area statica formed by the nucleus magnocellularis and ventral nucleus presented spontaneous activity, which increased in frequency and amplitude with both clockwise and counter clockwise rotatory stimulation. In addition the nucleus magnocellularis responded to acoustic stimuli. Labyrinthectomy carried out in several ways demonstrated that signals arising in one semicircular canal were transmitted to the area statica of both sides. An extensive area of the reticular formation of both sides exhibited spontaneous activity, which also increased in frequency and amplitude with both clockwise and counter clockwise rotatory stimulation. The results showed that the signals from one lateral semicircular canal are transmitted to the reticular formation of both sides. The lateral ampullary nerve at rest exhibited spontaneous activity, which increased in frequency and amplitude with rotatory stimulation producing ampullopetal flow. When the stimulus produced ampullofugal flow, the spontaneous activity diminished considerably or disappeared. The importance of these results for understanding the evolution of the vestibular system is discussed.

Ramon y Cajal (1952–1955) described in mammals a crossed root of primary vestibular fibers, which he assumed to terminate in the vestibular nuclei. The origin and termination of this root were the center of much controversy (see the comprehensive review by Rasmussen, 1946) until the studies of Rasmussen (1946, 1953, 1960) demonstrated that the root corresponds to the crossed component of the well known olivocochlear bundle. Recent studies by Brodal (1960) and Carpenter (1960) substantiated the opinion that in mammals no primary vestibular fibers cross to the vestibular nuclei of the opposite side.

Commissural secondary fibers connecting the vestibular nuclei of one side with those of the other side are described in mammals by several authors (Gray, 1926; Rasmussen, 1932; Ferraro, Pacella & Barrera, 1940). The functional significance of the commissural fibers is unknown, although Gray (1926) suggested that they may play a role in timing and coordinating sensory signals between the vestibular nuclei of both sides. This opinion has been criticized on the grounds that no evidence of commissural fibers can be

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[2] Now at Lund, Sweden.

demonstrated in the cat by electrophysiological recordings (Gernandt & Thulin 1952 Gernandt Iranyi & Livingstone 1959) DeVito Brusa & Arduini (1956) however have shown Deitersian units responding to electrical stimulation of the contralateral Deiters nucleus Gernandt (1960) suggested that the commissural fibers may be inhibitory and that this may be important for the neural mechanism of vestibulo ocular reflex arc

Numerous vestibular connections to both ipsilateral and contralateral reticular formation of the medulla and pons of mammals have been described by several authors (Papez 1926 Lorente de No 1933 Buchanan 1937 Ferraro Pacella & Barrera 1940 Scheibel & Scheibel 1958 Brodal 1960 and others) The connections are formed mainly by secondary neurons originating in the vestibular nuclei but ipsilateral primary connections are also described (Carpenter 1960) Physiological studies confirming the vestibulo reticular connections were made by several investigators (Spiegel 1929 Lorente de No 1933 Kempinsky & Ward 1950 Gernandt & Thulin 1952 Gernandt Iranyi & Livingstone 1959) It is generally accepted that these connections play an essential role in the neural mechanism underlying postural reflexes and the vestibulo ocular reflex arc

Crossed vestibular fibers to the area statica (nucleus magnocellularis and ventral nucleus) and reticular formation of amphibians are not thoroughly known Kappers Huber & Crosby (1960) mentioned that crossed vestibular fibers terminate in the ventral nucleus of the frog and Deganello (1899) described also in the frog a crossed vestibular root However the evidence regarding its origin and termination is debatable Further information regarding crossed vestibular fibers in amphibians is important for understanding the evolution of both cochlear and vestibular systems in mammals including man

The purpose of the experiments reported here is to find the electrophysiological correlate of the crossed vestibular root which has been described anatomically in the frog

METHODS

Leopard frogs (*Rana pipiens*) immobilized with *d* Tubocurarine chloride (1 mg per 100 g of body weight) served as experimental animals Two types of preparations were made one for recording from the area statica and reticular formation the other from the lateral ampullary nerve The area statica of the frog is formed by the nucleus magnocellularis and the ventral nucleus The former located in the most dorsal part of the medulla is considered to be an auditory center (Kappers Huber & Crosby 1960) The ventral nucleus located more ventrally and medially is considered to be essentially vestibular (Kappers Huber & Crosby 1960) For recording from either the area statica or reticular formation the cerebellum and fourth ventricle were exposed by an occipital approach It is convenient but not essential for a steady maintenance of the preparation to preserve the choroid plexus which covers the roof of the fourth ventricle

The frogs were pinned down rigidly on a cork board mounted on a rotating device (turned by hand) so that the lateral semicircular canals were in optimum position for rotary stimulation.

The active electrode for exploring the static area and reticular formation consisted of an enameled nichrome wire of about 100 μ diameter, mounted in a micromanipulator. The electrode was advanced slowly into either the nucleus magnocellularis or ventral nucleus or reticular formation until spontaneous activity could be detected by the oscilloscope or a monitoring loudspeaker. If this activity was modified by clockwise and counterclockwise rotation, then both motion of the rotating device and responses were displayed on a dual beam oscilloscope and photographed. Further recordings were then made after removing or cauterizing first one and then the other labyrinth. After completion of the experiment an electrolytic lesion was produced for tracing the tip of the electrode in the histologic preparations.

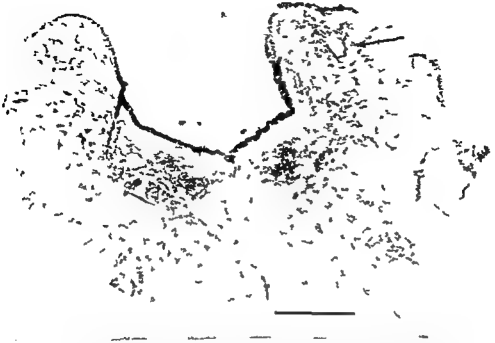
The surgical approach for the lateral ampullary nerve consisted in evisceration of one orbit and removal of the bony partition between this and the labyrinth. The ampullary nerve was exposed in its whole length, cut at the level of the utriculus and mounted in a small double hook stainless steel electrode. During recordings from the ampullar nerve the frog was in a supine position.

RESULTS

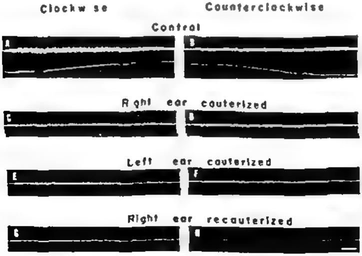
Recordings from nucleus magnocellularis

A section of the medulla passing through the nucleus magnocellularis and showing an electrolytic lesion in the right side is presented in Fig. 1. The recordings of this area exhibited spontaneous activity which increased in frequency and amplitude to both acoustic stimuli and rotatory motion in either clockwise or counterclockwise direction. The spontaneous activity and responses provoked were not modified after sectioning the V, VII, IX and X cranial nerves of both sides. No attempt was made to study the origin and projection of auditory signals into the nucleus magnocellularis.

The responses to both clockwise and counterclockwise rotation are illustrated in Fig. 2A and 2B respectively. Electrocoagulation of the right labyrinth eliminated responses to clockwise (ipsilateral) rotation (Fig. 2C). The persistence of responses to counterclockwise rotation (Fig. 2D), apparently associated with ampullopetal flow in the left lateral semicircular canal, indicates that each lateral ampullary nerve is projected bilaterally into the nucleus magnocellularis. The findings, however, do not prove whether the projection is through primary, secondary fibers or both. Electrocoagulation of the left labyrinth eliminated the responses to counterclockwise rotation (Fig. 2E). The reappearance of clockwise responses (Fig. 2F) was interpreted as recovery from incomplete destruction of the right labyrinth. A second electrocoagulation of this labyrinth suppressed permanently all responses (Figs. 2G and 2H). Persistence of responses due to incomplete labyrinthectomy was confirmed histologically in one frog.



o 1 Fro„ L 10 Cross section of the me lulla Arro v po nts to the electrol t e lesion locate l in ɜ right nucleus ; agnocellulari Tl e re po ses of th s area are shown in l ig The ı arker of s ı l sub equent photon cro raphs ı 0 mm N ls stain



I ıc I r g l 1 Re pı n es rec rde l fron right nucleus n agnocellular s to rotatory stin ulation f r explanatio see text) In thi an l sul quent records a clockwi e rotation l ıgr ale l l y a ce ll g ll e l cate l bel w the tracing Counterclockwi e rotati n is ignal l by a le cen l n„ l ne Ti ne n arker for all rec r l 10(n ec

Fig. 3. Frog E 102. Cross section of the medulla showing electrolytic lesion in the right ventral nucleus. Arrow points toward the area where the electrode penetrated the right side of the floor of the fourth ventricle. The responses of this area are shown in Fig. 4. Hematoxylin–eosin.

Recording from ventral nucleus

Fig. 3 shows a section of the medulla passing through the ventral nucleus of the VIII nerve in one preparation. The arrow points toward the area where the electrode penetrated the right side of the floor of the fourth ventricle. This area exhibited spontaneous activity, which increased with both counterclockwise (Fig. 4A) and clockwise rotation (Fig. 4B). The counterclockwise (contralateral) responses were not modified after electrocoagulation of the right labyrinth (Fig. 4C), while the responses to clockwise rotation disappeared (Fig. 4D). This finding indicates that the ventral nucleus, like the nucleus magnocellularis, receives impulses from both lateral semicircular canals. This opinion was substantiated when electrocoagulation of the left labyrinth suppressed completely both spontaneous activity and provoked responses (Fig. 4E and 4F).

Recording from reticular formation

An extensive area of the reticular formation presented spontaneous activity, which increased in frequency and amplitude with rotatory motion in either direction. Fig. 5 shows the electrode's placement in the left medial reticular formation of one frog. The responses to rotatory stimulation are presented

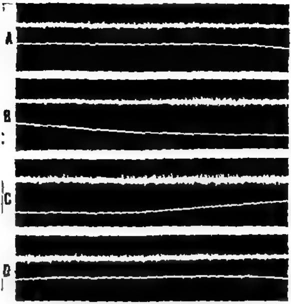


Fig. 7 Frog A 1093 Responses recorded from left horizontal ampullary nerve Animal in supine position At rest the nerve exhibited spontaneous activity (*A*) Counterclockwise rotation, which starts at the end of *A* and continues in *B*, produced inhibition of spontaneous activity Notice that the animal is in supine position and consequently a counterclockwise rotation produces ampullofugal flow in the left semicircular canal Note postrotatory excitation in the last half of *B*. After completing this rotation, spontaneous activity reappeared Clockwise rotation (*C*) caused ampullopetal flow in the left semicircular canal associated with increase in frequency of spontaneous activity After completion of this motion, the spontaneous activity recovered original frequency discharge

the neural mechanism underlying the vestibulo-ocular reflex arc (Lorente de Nó, 1933, 1938, Lorente de Nó & Berens, 1959, Spiegel, 1929, Szentágothai, 1950) and postural reflexes (see the comprehensive review by Gernandt & Gilman, 1959)

ZUSAMMENFASSUNG

Die gekreuzte vestibulare Wurzel zur Area statica und Formatio reticularis wurde bei Froschen mit Hilfe elektrophysiologischer Methode untersucht

Die Area statica, die vom Nucleus magnocellularis und Nucleus ventralis gebildet wird, zeigte spontane Aktivitat, die bei rotatorischer Reizung im Uhrzeigersinne und in der entgegengesetzten Richtung an Frequenz und Amplitude zunahm Ausserdem reagierte der Nucleus magnocellularis auf akustische Reize. Labyrinthektomie, die auf verschiedene Weise ausgefuhrt wurde, ergab, dass Signale, die in einem Canalis semicircularis entstehen, zu der Area statica auf beiden Seiten weitergeleitet werden

Ein ausgedehntes Gebiet der Formatio reticularis beider Seiten zeigte spontane Aktivitat, die bei rotatorischer Erregung im Uhrzeigersinne und in der entgegengesetzten Richtung auch an Frequenz und Amplitude zunahm. Die Resultate ergaben, dass die Signale von einem lateralen Canalis semicircularis zu der Formatio reticularis beider Seiten übermittelt werden

Der Nerv zur lateralen Ampulle zeigte bei Ruhe eine spontane Aktivitat, die bei otatorischer Reizung an Frequenz und Amplitude zunahm, wenn die Reizung mpullopetale Strömung hervorrief Wenn der Stimulus ampullofugale Stromung erursachte, nahm die spontane Aktivitat betrachtlich ab oder verschwand ganz

Die Bedeutung dieser Resultate fur das Verständnis der Entwickelung des vesti ularen Systemes wird diskutiert

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950 East 59th Street, Chicago 37, Ill, U S A

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AN OPERATIVELY TREATED CASE OF OBJECTIVE TINNITUS

G. HERBERTS
Umeå, Sweden

From the Department of Otolaryngology (Head: Prof. G. Herberts), Royal Medical School, Umeå

A case is reported of extreme objective tinnitus combined with headache in which phonographic recording and carotid angiography was carried out. Arterio-venous fistulas between a. occipitalis as well as a. meningea media to the sinus transversus. Ligature of a. carotis ext. was carried out, resulting in the practical elimination of noise and headaches (result still holding 7 months after operation). In the discussion the significance of thorough and complete examination in severe cases of tinnitus is stressed.

In the large group of patients suffering from tinnitus there appears every so often a case with so called *objective tinnitus*; a large number of such cases has already been reported on in the literature. The findings of auscultation of the cranium have received particular attention in neurological literature and have been interpreted as depending on intracranial vascular lesions. When the noise is localised in one ear and is thought of by the patient as an ear sickness the tinnitus is sometimes so strong that it can even be heard by others in the patient's neighbourhood. Such a case is reported on below, where the patient was freed from the symptoms by operation (ligature of carotis ext.).

CASE REPORT

P. H. P. (no. 563/60), 59 year old telephone engineer. Hereditary background nothing of interest. Eight years ago ulcus duodeni. After diet trouble free until last six months when reappearance of ulcer verified by X-ray. Managed well, however, by returning to dieting. In December 1958, slow beginning of trouble in form of tinnitus in the right ear in time with the pulse. Trouble abated from time to time. In April 1959 increased trouble by now continuous and interfering with sleep; sometimes the noise was so pronounced that even patient's wife could hear it when lying at his side in bed. Occasionally slight headaches. No general symptoms. The noise and consequent disturbances to sleep, together with headaches, meant he was unable to work in the latter part of this period.

Status: Strong man in good general condition. Heart physically normal. Blood pressure 140/80.

Ears: Normal ear drums.

Audiogram normal. Pulses could be felt behind the right ear. One could

FIG. 1. Angiography in a. carotis ext. dx. Arterio-venous fistula between a. carotis ext. and sinus transversus.

auscultate a strong hissing noise above the processus mastoideus dx. which vanished upon compression of the a. carotis ext. dx. X-ray of right ear showed normal cell system. Angiography in the a. carotis ext. dx. (Greitz) (see Fig. 1): arteriovenous connection between a. carotis ext. dx. (a. occipitalis, a. meningea media) and sinus transversus.

Further examination included angiography in the a. carotis int. dx. but revealed no observable connection between its branches and the arterio-venous fistula.

Phonogram registered retroauricularly on the right side a secondary noise of high frequency with a stronger systolic component beginning 10 centiseconds after the initial tone and a diastolic component of diminuendo type. These findings could correspond to an arterio-venous fistula or aneurysm (Linderholm). Examination was completed with recording over a. carotis bilat. 5 cm above the jugulum as well as over the basis cordis. The secondary noise recorded retroarticularly on the right side was not noticed elsewhere.

Acting on the diagnosis fistulae arterio-venosa arterio-occipitalis et meningea media dx. a ligature of the carotis ext. (local anaesthetic) was carried out. The vessel was adherent to its sheath by a small hematome round it (from angiography). Before, during and after the closure of this ligature the pho-

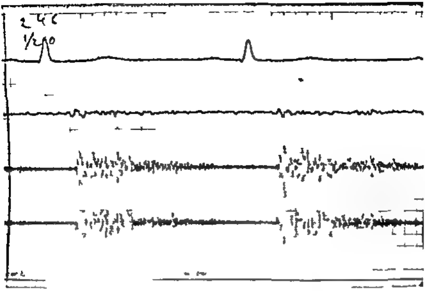

Fig. 2. Phonogram immediately before ligature.

nogram was recording continuously retroarticularly from the right planum mastoideum (see Fig. 2, 3). It will be noticed that while the amplitude diminished considerably it did not totally disappear. The patient stated that the noise was absent. The bared vena jugularis was also compressed but *without any change in the phonogram. Further ligature was thus not attempted.* The post operative course was free of complications. In the days following the operation the patient stated that the noise had completely vanished and that the headaches were considerably relieved, sometimes even ceasing altogether.

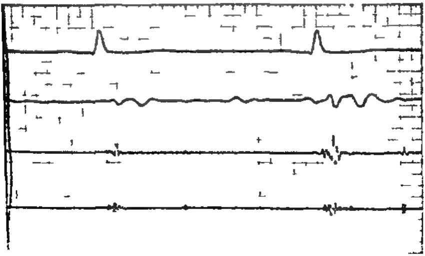

Fig. 3. Phonogram immediately after ligature (of a. carotis ext.).

After examination 7 months later the patient had fully returned to work no trouble with noise headaches almost completely vanished though occasional slight attacks

DISCUSSION

In most cases of objective tinnitus noise is one of a number of other neurological findings and thus cases are often treated by neurologists and neurosurgeons The symptom is often described in neurological literature From the ear consultant s point of view it is important to bear in mind the possibility of an intracranial vascular lesion as a source of the noise in the treatment of the large group of tinnitus cases The patient s own description of the symptom may often be an important clue while auscultation or palpation can give objective findings of great value Such examinations therefore ought to be included in the routine examination of a tinnitus case—something which is often passed over As Engstrom pointed out phonographic recording by the method of Mannheimer as well as angiography should be part of the pre diagnostic work in such cases

The noise synchronised with the pulse and heard in the ear can be considered to be conducted vascular noise which may occur either peripherally or intracranially In another communication the significance of thin vascular strings in the middle ear as a cause of noise has been discussed In one group of cases the reason may be that there is a dilated blood vessel in the region of the ear and that compression of the vessel is accompanied by a cessation of the noise There is a third group in which the cause lies in intracranial vascular affections (aneurysm arterio venous fistulae) from which the vascular noise is conducted to the ear In this latter group a compression of the large vessels of the neck can be accompanied by a reduction or even total cessation of the noise (cf the above case)

It is possible that one group of tinnitus cases in which the origin is vascular have nevertheless negative auscultation and palpation findings and are therefore not diagnosed as objective tinnitus Extreme cases of such tinnitus are often a problem to the ear consultant The noise for these patients can be so severe that it gives rise to thoughts of suicide Before deciding to open the labyrinth or possibly to destroy it in these cases a thorough angiographic examination both of carotis and vertebralis should be carried out

ZUSAMMENFASSUNG

Ein Fall von hochgradigem objektivem Tinnitus mit Kopfschmerzen vereinigt wird vorgelegt auf dem phonografische Registrierung und Carotisangiographie ausgeführt worden ist Arteriovenose Fisteln zwischen A occipitalis und A meningea med a nach Sinus transversus Ligatur von A carotis ext brachte mit sich daß sowohl das Sausen als auch der Kopfschmerz so gut wie vollständig verschwand (das

Resultat war 7 Monate nach der Operation bestehend) In der Diskussion wird die Bedeutung hervorgehoben, daß schwere Tinnitusfalle Gegenstand einer sorgfaltigen Untersuchung werden

RÉSUMÉ

Un cas de grave tinnitus objectif accompagné de migraine est présenté, sur lequel enregistrement phonographique et angiographie de carotis ont été effectués Des fistules arterioveineuses entre a occipitalis et a meningea media jusqu'à sinus transversus Ligature d'a carotis ext a donné que non seulement le bruissement mais aussi la migraine est disparue presque tout à fait (le resultat est permanent sept mois après l opération) Dans la discussion est indique l'importance d une examination minutieuse des cas de grave tinnitus

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Dept of Otolaryngology, Royal Medical School, Umeå

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FOREIGN BODIES IN THE OESOPHAGUS

Complications of Diagnostic Oesophagoscopy and Their Treatment

Kledoë Sorensen and F. Welin
Copenhagen, Denmark

From the E. N. T. Department (Head: J. Falbe-Hansen, M.D.), Copenhagen City Hospital

INTRODUCTION

A foreign body in the oesophagus may in some cases be a danger to life. Moreover, its removal may involve considerable difficulty and constitute a risk in itself.

Since a large number of cases occur in a big city and since the literature on the complications of foreign bodies and their removal is rather meagre, we felt that it might be of interest to analyse the material seen during a 6 year period at the E. N. T. Department of the Copenhagen City Hospital.

Previous Investigations

Terracol & Sweet have described how the prognosis of foreign bodies in the oesophagus has been completely changed by improvements in instruments and operative technique. Before the turn of the century the mortality was 58%, falling in the early years of the present century to 8.9%. Recent advances are due mainly to the American school (Chevalier Jackson) which has reported a mortality of less than 1.2% in the most recent series.

Analysing the cases of foreign bodies treated at Chevalier Jackson's clinic during the period 1941–46 Norris found a total of 191 to be localized to the hypopharynx and oesophagus. The most common objects were bones (70 cases), coins (40 cases), safety pins (30 cases), meat (23 cases) and dentures (5 cases). About two thirds were lodged in the upper part of the oesophagus. Half the patients were children. The foreign bodies were removed by oesophagoscopy except in 4 cases (3 removed by a special kind of forceps under fluoroscopy and one was pushed down into the stomach by a rubber catheter). One death occurred because of perforation of the aorta by a bone. Among other complications he mentions a case of mediastinitis treated by cervical mediastinotomy and penicillin, retropharyngeal abscess and 2 cases of cervical perforation with oozing of the contrast medium into the mediastinum. The latter healed without reaction during penicillin therapy. All the complications were caused by the foreign bodies.

Tzetzu *et al.* (1957) in the course of 7 years had 527 cases of foreign bodies in the oesophagus, most often coins and buttons (145 cases), bones (132

cases) and meat (112 cases). A total of 52% were located in the upper part and 42% in the mid oesophagus. Half the patients were children. The foreign bodies were removed by oesophagoscopy in all cases but there was one in which a denture had to be removed by oesophagotomy. Four deaths occurred because of perforation and mediastinitis (three caused by the foreign bodies and one by the oesophagoscope). In addition there were seven instances of oesophageal abscess, three of mediastinitis, two of ulcero-purulent oesophagitis, one of ulceration and haematemesis and one of excessive granulations. No mention is made of the treatment of the complications.

Matheson (1949) and Barrett (1951) have reported a somewhat lower incidence of complications, Clerf (1940) a somewhat higher.

Several authors (Seybold *et al.*, Heald, Rietz & Werner, Mathewson *et al.*) have studied perforations of the oesophagus in general, partly perforations caused by foreign bodies and their treatment and partly perforations occurring during diagnostic oesophagoscopy, and finally the more uncommon cases due to external injury or spontaneous rupture. All these authors have reported the number of perforations during a given period but regrettably not the incidence of complications to foreign bodies or to oesophagoscopies.

The oesophagoscope is stated to be the most common cause of perforation. The risk of perforating the oesophagus by the oesophagoscope is particularly great in the presence of pathological conditions such as tumours, ulcerations, strictures and achalasia, especially if the procedure is supplemented by removal of biopsy, bougienage or dilatation. According to Seybold *et al.* the perforations were caused by dilatation in 30% and according to Doig in 35%, while foreign bodies were responsible in 12.5% and 26% respectively. The most common cause was the oesophagoscope in both, 37% and 34% respectively.

Small superficial mucosal injuries are fairly common and usually heal without complications. Owing to the ever present bacterial flora, however, they may occasionally give rise to serious infection in the oesophageal wall or the periesophageal tissue, whence it may spread to the periesophageal space, mediastinum and pleural space. In the case of profound injuries, especially perforation of the entire wall, there is always a risk of severe, often alarming infection. More uncommon but usually fatal complications are perforation of the great vessels (Clerf) or the heart (Peeler). Prior to the antibiotic era the mortality of perforation was very high, especially with conservative treatment (Pearse: 27% with early cervical mediastinotomy and 87% with conservative treatment; Orton: 5 out of 6 patients died on conservative treatment). Although the introduction of antibiotics has improved the prognosis, deaths still occur, especially in cases of perforations which are large or are not immediately diagnosed (Mathewson: 11 out of 54; Rietz & Werner: 7 out of 24; Heald: 3 out of 10; Doig: 4 out of 16). The perforation is most often localized to the cervical portion of the oesophagus (Terracol & Sweet: 70%).

Practically all authors emphasize that the most important thing in diagno-

sing perforation is always to bear in mind the possibility of its presence in cases of foreign bodies and oesophagoscopies Pain and pronounced dysphagia are nearly always present at once vomiting (in some cases blood stained) is common Fairly soon pyrexia will arise In cases of perforation in the upper portion of the oesophagus the pain usually affects the lower neck in some cases radiating to the back Most patients show subcutaneous emphysema antero laterally on the neck later tender swelling at this site When the perforation is in the mid oesophagus the pain is usually localized to the back as a rule there are pulmonary symptoms and not infrequently shock If the injury is in the lower portion there is generally pain in the epigastric region muscular defense and in some cases shock X ray examination is of the utmost importance (as emphasized particularly by Huizinga) Retro oesophageal air (Minnegerode's sign) usually indicates perforation it is later accompanied by an increased width of the space between the trachea and spine X ray examination using contrast medium (not barium however but lipiodol or the like) is important to locate the perforation Oesophagoscopy is recommended by some authors (*Colman Terracol & Sweet*) while others (Doig Overstreet & Ochsner) advise against it because of the danger of further tearing the oesophageal wall

Bisgaard and later Colman & Doig have classified the perforations into 3 types

(1) Small perforations (e g by pins or fish bones) and mucosal tears

(2) Perforations due to slow erosion (e g by coins or by pressure necrosis following oesophagoscopy)

(3) Large sudden perforations due to the oesophagoscope or a large foreign body

In Groups 1 and 2 there is a chance of restricting the infection and thus of a successful conservative therapy In Group 3 cases there will be rapid contamination of the tissues and spread of the infection so that conservative treatment is insufficient Most authors try conservative treatment for small perforations diagnosed at an early stage especially if they are high seated A few (Rietz Colman Lederer) prefer mediastinotomy in all cases as soon as the perforation has been diagnosed

Conservative measures comprise sparing the oesophagus i e parenteral feeding during the first days and then feeding through a gastric tube In addition large doses of antibiotics Careful oral and dental hygiene is important (Chamberlain)

Surgical treatment comprises closure of the perforation (if the diagnosis has been made within 6 12 hours) and drainage of pus and secretion In cases of high seated perforation (up to the level of the 4th thoracic vertebra) the procedure is cervical mediastinotomy Where the perforation is lower down the transthoracic approach is preferable Early treatment of shock and tension pneumothorax (or pneumo mediastinum) is of vital importance This treatment should be supplemented by the measures mentioned under conservative treatment

TABLE 1 *Foreign bodies by age, sex and treatment*

Age groups years	Sex		Foreign body removed by oesophagoscopy			Spontaneous discharge		
						Through the intestine		
	Males	Females	Removed by forceps	Pushed down into stomach	Vomiting	Clinically confirmed (obstruction)	Confirmed by X rays (no obstruction)	Mucosal tear (no X rays no obstruction)
0–9	24	27	38	3	2	0	8	0
10–19	7	2	6	[illegible]	1	0	1	1
20–29	6	4	5	[illegible]	2	0	1	0
30–39	[illegible]	7	12	0	1	1	1	0
40–49	7	23	17	[illegible]	4	1	5	3
50–59	15	21	25	0	3	1	2	5
60–69	12	23	25	[illegible]	2	2	1	5
70–79	10	22	25	[illegible]	2	2	2	1
80–89	2	4	3	0	1	1	1	0
90–99	[illegible]	1	1	0	0	0	0	0
	91	131	157	5	18	8	22	15
Total	225							
No. of patients submitted to oesophagoscopy	200		157	5	4	5	14	15

Present Series

During the period 1955–1960 a total of 225 definite cases of foreign bodies or mucosal injuries due to the passage of a foreign body through the oesophagus were seen in the E.N.T. Department of the Copenhagen City Hospital. The sex ratio was 60% females and 40% males. The youngest patient was 7 months of age and the oldest 90 years. As evident from Table 1, foreign bodies are very common not only in young children but also in patients over 40 years of age. Children are apt to put everything into their mouths and carelessness is the explanation of the large number of foreign bodies in this age group. In the middle-aged and elderly patients the main cause is deficient chewing of the food and reduced sensitivity in the teeth and palate due to dentures (emphasized by Jackson, Terracol & Sweet, Tzetzu, Barrett, Norris and others). A very large proportion of our patients had dentures, but we are unable to give the exact number because of data lacking in the records. Pathological conditions of the oesophagus are often the explanation of the lodgement of small particles of food and of frequent recurrences.

We found pathological changes in 19 cases (8.0%). In 6 (5 with strictures caused by corrosion and 1 with cardiospasm) the patients were aware of the

TABLE 2. *Type and age groups of foreign bodies. Total 225 cases*

Type of foreign body	Age in years					
	0–9	10–19	20–29	30–39	Over 40	Total
Poultry bone		2	1	[illegible]	[illegible]	36
Fish bone		1		1	27	29
Other bones		1		3	23	27
Piece of meat		1	2	4	44	51
Plum stone	1			1	5	7
Other food particles			1		6	7
Coins	38	4				42
Table knife			2	3		5
Partial denture			2		2	4
Button	3					3
Ring	1				1	2
Brooch	2					2
Flute	2					[illegible]
Safety pin	1					1
Nail			1			1
Drawing pin	1					1
Plastic car	1					1
Toy key	1					1
Bottle cap			1			1
Broken glass					1	1
Metal chip					1	1

condition and all of them had previously had foreign bodies removed. In 13 the present event was the reason why the abnormality was recognized. Six had benign strictures, 3 diverticula, 2 cardiospasm, 1 a benign polyp and 2 malignant tumours. In a number of cases intoxication had no doubt been a contributory cause, and 3 patients were mentally deranged (had eaten table knives as a protest action against imprisonment).

The nature of the foreign bodies was extremely varied (cf. Fig. 2). Bones were the most common ones (40.9%). Among poultry bones, chicken bones predominated. The fish bones were in 16 cases from cod, in 12 from plaice and in one case from a mackerel. Incidentally, the suspicion of fish bones in the oesophagus was the most common cause why the patients were referred to us. In the majority of cases the fish bones were lodged in the pharynx and could be removed without much difficulty. None of the patients had oesophagoscopy because of a suspicion of herring bones, the complaints subsided after observation for a short time. Lumps of meat (including giblets) made up the second largest group of foreign bodies (22.7%). These as well as bones occurred practically speaking only in adults, which is rather peculiar when bearing in mind how often children bolt their food. Part of the explanation must be that the children's food is often carefully selected and cut by the parents. The third largest group was coins (18.6%), occurring, as might be

TABLE 3 *Level of foreign body in oesophagus*

Level	Age in years						Percentage distribution
	0–9	10–19	20–29	30–39	Over 40	Total	
Cervical (high seated)	35	4	5	8	100	152	c 68%
Upper thoracic level (middle)	8	2	0	1	16	2	c 12%
Lower thoracic level (low)	6	2	3	4	11	26	c 11%
Uncertain level	2	1	2	2	13	20	c 9%

expected only in children in whom they were twice as common as all other foreign bodies combined. Needles, safety pins and buttons were less common than in most previous series.

The level of the foreign bodies (or of the tears) in the oesophagus may be seen from Table 3. It corresponds quite closely to the three physiological constrictions. In more than two thirds of the cases the foreign bodies were high seated, i.e. in the cervical part of the oesophagus at or just below the sphincter (Matheson 66%, Ferracol & Sweet 80–90%).

The symptoms varied with the patient's age, the nature of the foreign body, its size and location, as well as the presence of complications, if any. Most of the infants were restless and crying; in 8 cases there was also salivation and spitting of mucus or milk. Mild respiratory embarrassment and cough due to overflow into the larynx occurred in a number of cases. More severe respiratory distress with stridor and cyanosis due to compression of the trachea was present in only one case. In the somewhat older children the main complaint in 6 cases was "tummyache". Five had no subjective complaints at all. In children over 4–5 years of age pain in the neck and refusal to eat were the most common symptoms. Unlike the babies these children could tell *their parents that they had swallowed a foreign body*. *However the* parents had nearly always seen the babies playing with the foreign body concerned and had a suspicion that they had swallowed it. Accordingly 90% of the children arrived for treatment less than 2 or 3 hours after swallowing the foreign body. Only one came more than 24 hours after. Among the adult patients the most common complaints were a sensation of a foreign body, pain (usually mid neck), dysphagia and partial or total obstruction. In the patients with total obstruction there was generally salivation, coughing and more or less marked dyspnoea due to the compression of the trachea by the foreign body and overflow of saliva into the larynx. On arrival 4 patients had elevation of temperature, but apart from that none had initial clinical signs of complications. In the adult cases treatment was instituted within 24 hours in 87%, within a day or two in 17 cases, within 3 days in 4 cases and within 4 days in 1 case. Only 1 of the patients who arrived for treatment after the course of 24 hours had complications (abscess of the oesophageal wall).

The diagnosis was obvious in a number of cases (obstruction). In cases of

TABLE 4 *Form of anaesthesia in oesophagoscopy*

Form of anaesthesia	Age in years 0–9	10–19	20–29	30–39	Over 40	Total	Percentage distribution
No anaesthesia	26	[illegible]	0	0	0	26	[illegible] 12%
Local anaesthesia	0	3	8	10	114	135	c 64%
General anaesthesia	24	5	2	[illegible]	18	52	c 24%

smaller foreign bodies, especially bones which occasioned only moderate pain and dysphagia, unchanged or exacerbated complaints during the time preceding admission indicated the presence of a foreign body, so did a feeling of pricking in the neck when the larynx was moved from side to side. In the presence of high seated foreign bodies there was occasionally oedema of the arythenoid regions on indirect laryngoscopy. X rays (without and with contrast) were important in all questionable cases. Out of our 225 patients 128 were X rayed, but in only 6 was there a divergence between the X ray and the clinical findings. In 2 cases (fish bones), where X rays showed a foreign body, oesophagoscopy showed only a tear. In 4 cases X rays did not show any foreign body, while oesophagoscopy revealed a fish bone, a chicken bone, and another two bones, all high seated. Some authors (e g Barrett) consider X rays of no use in visualizing fish bones. Like Goldman and Norris, we found a marked conformity between the X ray and endoscopic findings, both in cases with fish bones and other bones. In children with few or uncharacteristic symptoms, X rays are, of course, of the utmost diagnostic importance. Since, moreover, the X ray findings may afford guidance for the treatment (orientation of pointed and sharp foreign bodies) and data regarding possible oesophageal pathology or complications (perforation), X ray examination is used as a routine preceding any oesophagoscopy in our Department.

Treatment

Attempts were made to remove the foreign bodies through the oesophagoscope in all cases. In 5 cases these attempts failed, in 4 the foreign bodies were inadvertently pushed down into the stomach, but were discharged spontaneously without complications. In the fifth case, that of a table knife with the handle in the stomach, the patient refused further oesophagoscopy after one unsuccessful attempt, and the knife had to be removed by gastrotomy. In no case was it necessary to perform oesophagotomy.

The form of anaesthesia will be seen from Fig 4. Local anaesthesia (tetracaine 1%) was generally supplemented by intravenous injection of 0.5–1.5 ml pethidine. A few years ago practically all our oesophagoscopies were performed under local anaesthesia or without anaesthesia (children). Now *most of the children (except the infants) and very apprehensive* and excited

TABLE 5 *Complications of foreign bodies and oesophagoscopies (not including diagnostic oesophagoscopies)*

	Number of cases with tear	Number of cases without tear
Air (behind the oesophagus)	1	1
Air + soft tissue shadow (between trachea and spine)	1	1
Air – increased soft tissue shadow – fever	3	1
Fever alone	–	5

patients have inhalation anaesthesia (by intubation) The same applies to patients with very large incisor teeth or with foreign bodies expected to give rise to difficulties

A total of 140 patients were treated on an out patient basis while 85 were admitted All the patients who had inhalation anaesthesia were admitted The same holds good of all patients with complications and with pathological conditions of the oesophagus Patients with oeosophageal tears and elevation of temperature were given antibiotics and a liquid diet All out patients and patients with spontaneous discharge of the foreign body were closely followed up until the complaints due to the foreign body or to the oesophagoscopy had cleared up

Complications

As is apparent from Table 1 200 patients had oesophagoscopy Since a few had this procedure 2 or 3 times a total of 213 oesophagoscopies were carried out on this group of patients and moreover on 22 due to a suspicion of foreign bodies (In these cases the oesophagus was normal and no X ray examination was made) During the same period another 121 diagnostic oesophagoscopies were carried out because of a suspicion of tumour stricture etc (Five of these procedures included bougienage 2 dilatation by the method of Starcke and 28 removal of biopsy specimen) Thus during the period mentioned a total of 356 oesophagoscopies were performed

The oesophagoscopies performed because of a foreign body or a suspicion of foreign body revealed mucosal tears with bleeding in 62 cases (26 4%) Most of these injuries were caused by the foreign body or manipulations with the foreign body Table 5 shows incidentally that 5 of the cases with oesophageal tears had shown X ray signs of perforation and that another 7 had signs of infection (fever) In all cases of perforation the foreign body was a cod bone and the site was the cervical oesophagus In 10 of these cases the complaints yielded to a few days on penicillin and liquid diet while 2 required mediastinotomy as the temperature did not drop and as vomiting slightly blood stained occurred after a few days conservative treatment In one of these cases the oesophageal wall was oedematous but there was no

infection of the surrounding structures. The patient could be discharged in good health 6 days later. In the other case there was a limited area of periоesophagitis behind the oesophagus. The drain could be removed at the end of 3 days. The patient (a 63-year old woman) had heart failure and chronic nephropathy. She was transferred to a department of medicine for treatment of these conditions, but died of coronary thrombosis 18 days after the operation (autopsy showed the oesophagus to be normal without any perioesophageal infection).

In 3 cases where oesophagoscopy failed to disclose a tear, X-rays showed signs of perforation in the cervical oesophagus. In one of these patients, who also had fever, there was an abscess in the oesophageal wall caused by a piece of meat which had remained lodged for 3 days. The other 2 cases were caused by cod bones (discharged spontaneously). In all 3 cases the complaints yielded within a few days to penicillin medication. The same was true of the 5 cases without tears, but with fever.

In the group of diagnostic oesophagoscopies there were only 4 cases of tears, and this was not accompanied by fever except in one. Another 3 had only fever. In all cases the complaints rapidly yielded to penicillin.

DISCUSSION

Considering the technical difficulties which are often encountered in extracting foreign bodies, due to mucosal oedema, bleeding, tears, incipient abscess formation, strictures, etc., it is amazing that serious complications were so rare in the present series (one case of oesophageal abscess yielding to penicillin and 2 cases of periоesophagitis which quickly healed after cervical mediastinotomy and penicillin therapy). The explanation is presumably the very easy access to prompt treatment in a big city combined with our intensive follow-up on all out-patients.

The available literature does not specify any analysis of the number of mucosal tears, neither due to foreign bodies (or their treatment) nor to diagnostic oesophagoscopy.

As already mentioned, oesophagoscopy performed because of a suspicion of foreign bodies in our series showed a large number of mucosal tears (26.4%). They were probably due mainly to foreign bodies, as also indicated by the very small number of tears (3.3%) found in diagnostic oesophagoscopy. When adequately treated, these tears heal in a few days.

SUMMARY

During the period 1955–1960 a total of 225 patients with foreign bodies in the oesophagus were treated at the E.N.T. Department of the Copenhagen City Hospital. Of these patients 27% were children. The most common foreign bodies were bones (40.9%), pieces of meat (27.7%) and coins (18.6%). The first two groups occurred, practically speaking, only in adults and the third group only in children. In m

than two thirds of the cases the foreign bodies were high seated Pathological con ditions in the oesophagus were responsible for the lodgement of the foreign body in 8 % During the period mentioned a total of 356 oesophagoscopies were performed 235 because of a suspicion of foreign bodies and 121 for other reasons Only a very few serious complications occurred (and none to the diagnostic oesophagoscopies) X ray examination was of great diagnostic importance Perforation occurred in 8 cases (caused by cod bones in 7) and only in the upper part of the oesophagus In 6 *of the cases the complaints subsided within a few days on penicillin (and liquid diet)* Two cases (of perioesophagitis) required cervical mediastinotomy One of these pa tients died but of a different cause and after the oesophageal disease had been cured

The number of mucosal tears (not specified in other series) was fairly large and in dubitably caused by the foreign bodies (26 4 % tears in the group of oesophagoscopy performed because of a suspicion of foreign body and only 3 3 % in the group of diagnostic oesophagoscopies) When adequately treated these tears quickly heal without complications

ZUSAMMENFASSUNG

In den Jahren 1955 1960 wurde auf der Ohrenabteilung des Stadtischen Kranken hauses in Kopenhagen 295 Patienten mit Fremdkorpern in der Speiserohre behandelt 27 % der Patienten waren Kinder Die gewohnlichsten Fremdkorper waren Knochen und Fischgraten 40 9 % Fleischstucke 22 7 % und Münzen 18 6 % Die beiden erst genannten Gruppen wurden meistens nur bei Erwachsenen gefunden die dritte Gruppe nur bei Kindern

In mehr als ⅔ der Fälle wurden die Fremdkorper hoch oben in der Speiserohre loka lisiert Pathologische Verhaltnisse in der Speiserohre als Ursache zum Festsitzen der Fremdkorper wurden in 8 % gefunden Es wurden im genannten Zeitraum 356 Ösophagoskopien gemacht 235 auf Verdacht und 121 diagnostische (be fundliche) Ösophagoskopien

Komplikationen sehr wenig ernsthafte und bei den befundlichen Ösophagoskopien keine waren sehr selten Röntgenuntersuchung ist fur den Befund sehr wichtig Per foration ist nur im oberen Teil der Speiserohre vorgekommen und nur in 8 Fällen (die 7 Fälle waren von Fischgraten verursacht) In 6 Fallen verschwanden die Un annehmlichkeiten bei Penicillinbehandlung und flussiger Kost in eine paar Tagen In 2 Fallen (periösophagitis) wurde eine cervical Mediastinotomie gemacht Der eine dieser Patienten ist an einem anderen Leiden gestorben und nachdem das Speiserohr leiden geheilt war

Die Anzahl der Schleimhautverletzungen (in anderen Untersuchungen nicht ange geben) war nicht gross und unzweifelhaft von den Fremdkorpern verursacht (26 4 % Risse in der Gruppe Ösophagoskopien mit Verdacht auf Fremdkorper aber nur 3 3 % in der Gruppe befundliche Ösophagoskopien) Diese Risse heilen sehr schnell ohne Komplikation bei zweckmassiger Therapie

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E. N. T. Department, Rigshospitalet, Blegdamsvej 9, Copenhag

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ZUR GRÖSSE DES EIWEISSTOFFWECHSELS DER GEWEBE DER COCHLEA

Autoradiographische Untersuchungen an Meerschweinchen nach Gabe von H 3 Leucin und H 3 Lysin

E. Koburg[1] und D. Plester

Aus dem Institut für Medizinische Isotopenforschung der Universität Köln (Leiter Prof. Dr. W. Maurer) und der Klinik für Hals-, Nasen- und Ohrenheilkunde der Medizinischen Akademie Düsseldorf (Direktor Prof. Dr. A. Meyer zum Gottesberge)

Die bisher am Innenohr durchgeführten histochemischen Untersuchungen zum Ferment- und Eiweißgehalt einzelner Gewebe stellen gleichsam Momentaufnahmen dar, die die Konzentration der jeweiligen Substanzen zum Versuchszeitpunkt angeben. Bei einer Aneinanderreihung mehrerer solcher zeitlich aufeinander folgender Einzelbilder sind Schlüsse auf den Ablauf der Stoffwechselvorgänge möglich.

Der ständige Auf- und Abbau von Gewebe- und Zellbausteinen kann demgegenüber eher mit Hilfe von radioaktiv markierten Substanzen verfolgt werden. Die autoradiographische Methode erlaubt dabei die Beobachtung von Stoffwechselvorgängen bis hinunter in subcelluläre Bereiche.

Ziel der vorliegenden Untersuchung war die Darstellung des Eiweißstoffwechsels der Cochlea des Meerschweinchens. Die Versuche wurden mit Tritium markierten Aminosäuren (H 3 Leucin, H 3 Lysin) durchgeführt. Dabei ergab sich u. a., daß die Ganglienzellen des Ganglion spirale cochleae den größten Eiweißstoffwechsel haben. Nur wenig geringer ist der Eiweißstoffwechsel der Stria vascularis. Relativ gering ist der Eiweißstoffwechsel der Sinnes- und Stützzellen des Cortischen Organs.

METHODISCHES

1. *Tierversuche*

Zu den Versuchen wurden Meerschweinchen beiderlei Geschlechts im Gewicht zwischen 240 und 280 g verwendet. Den Tieren wurde jeweils 10 mC pro H 3 Leucin (spez. Akt. 3000 mC/mM) bzw. pro H 3 Lysin (spez. Akt. 1000 mC/mM) (Birkofer & Hempel 1960) intraperitoneal injiziert. Zwei Stunden nach Applikation der radioaktiv markierten Aminosäuren wurden die Tiere in Äthernarkose durch Öffnung des Brustkorbes und Durchschneiden beider Herzkammern getötet. Nach Trepanation der Bulla

[1] Jetzt: Klinik für Hals-, Nasen- und Ohrenheilkunde der Medizinischen Akademie Düsseldorf.

und Entfernung des Stapes wurde das Labyrinth zur Fixierung in kaltes 6%iges Formalin mit 5% Trichloressigsäurezusatz eingelegt. Da es sich um junge Tiere handelte, bewirkte der Trichloressigsäurezusatz in 2–3 Tagen gleichzeitig eine ausreichende Entkalkung des Labyrinthknochens. Dem Fixierungsmittel wurde inaktives Leucin bzw. Lysin zugesetzt, um adsorbierte markierte AS auszutauschen. Um eine gute Durchdringung des Präparates mit dem Einbettungsmittel zu ermöglichen, wurde die Schnecke im Bereich des runden Fensters breit eröffnet. Nach Durchlaufen der Alkoholreihe wurde die Cochlea im Vakuum in Paraffin eingebettet.

2. *Autoradiographische Technik*

Für die Autoradiogramme (ARG) wurden 5 μ dicke Längsschnitte der Cochlea verwandt, *von denen die den Modiolus treffenden* ausgewählt wurden. Ein Teil der Autoradiogramme wurde nach der stripping film-Technik (Pelc 1947, Boyd 1947) mit Kodak AR 10 hergestellt und 2–6 Wochen exponiert. Zusätzlich wurden Präparate mit der flüssigen Emulsion Ilford G 5 hergestellt. Hierbei genügten Expositionsdauern von 3–20 Tagen. Nach photographischer Entwicklung wurde ein Teil der Schnitte durch die Photoschicht hindurch mit Hämatoxylin-Eosin gefärbt. Weitere Einzelheiten der Technik bei Maurer (1959), dort weitere Literatur.

Da die maximale Reichweite von Tritium 0,5 mg/cm² oder 5 μ in nassem Gewebe beträgt, die überwiegende Mehrzahl der emittierten β-Teilchen aber eine noch wesentlich kleinere Reichweite haben, erreicht man bei Verwendung dieses Isotops im Autoradiogramm eine fast punktförmige Abbildung. Das autoradiographische Auflösungsvermögen bei Anwendung von Tritium beträgt etwa 2/3 μ (vgl. Meyer zum Gottesberge 1961).

3. *Quantitative Auswertung durch Silberkornzählung*

Durch Auszählung der Silberkörner pro μ^2 Gewebefläche ist ein quantitativer Vergleich des AS-Einbaues in den einzelnen Geweben und Zellen möglich. Zur Auszählung wurden Okularnetzmikrometer verwandt, wobei ein Einzelquadrat bei Ölimmersion einer Fläche von 16 μ^2 entsprach.

Pro Zellart bzw. pro Gewebe wurde für jede der verwandten Aminosäuren jeweils 70–100 Einzelquadrate (=1120–1600 μ^2) ausgezählt. Sofern Zählungen nicht ausdrücklich an Zwischensubstanzen erfolgten, wurde so vorgegangen, daß wenigstens 50 Einzelzellen erfaßt wurden. Die Summen aller pro Zell- oder Gewebeart festgestellten Silberkornzahlen liegen zwischen 1000 und 3000. Der statistische Fehler der mittleren Silberkornzahlen pro μ^2 in Tabelle 1 bewegt sich also zwischen 1,8 und 3,1 Prozent.

Der subjektive Zählfehler konnte durch mehrmaliges Auszählen gleicher Areale, insbesondere auch durch Kontrollpersonen bestimmt werden. Bei einem Zählergebnis von durchschnittlich 20–40 Sk pro Zählquadrat war er immer kleiner als 10%.

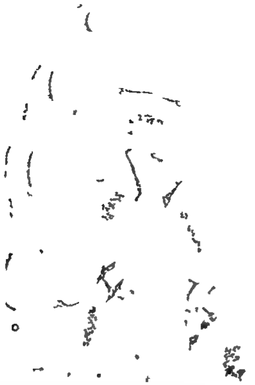

Abb 1 Autoradiogramm der Cochlea eines Meerschweinchens 2 St 1 nach Gabe von H 3 Leucin Starke Schwarzung über den Ganglienzellen des Ganglion spirale cochleae weniger starke Schwarzung über der Stria vascularis relativ geringe Schwarzung über dem Cortischen Organ 30 fach stripping film Schnitt *ungefarbt*

I ERGEBNISSE MIT H 3 LEUCIN

1 *Übersicht uber die Schwarzungsverteilung innerhalb der Cochlea*

Abb 1 zeigt eine Übersichtsvergroßerung eines ungefarbten Autoradiogrammes der Cochlea Die Ganglienzellen des Ganglion spirale cochleae weisen die starkste Schwarzung auf Die ubrigen Gewebe sind schwacher geschwarzt und zwar nimmt die Silberkorndichte in der Reihenfolge Stria vascularis Reißnersche Membran Cortisches Organ Limbus spiralis ab Über der Membrana tectoria finden sich keine Silberkorner Die Schwarzungsverteilung uber den einzelnen Geweben soll im folgenden eingehender beschrieben werden

Ganglion spirale cochleae (Abb 1 u 2)

Die Spalte 2 der Tabelle gibt die uber den einzelnen Zellarten festgestellten Silberkorndichten wieder Die Ganglienzellen weisen mit 2 46 Silberkorner (S K) pro μ^2 und 20 Tage Belichtungszeit die großte mittlere SK Dichte auf Der Neurit ist frei von Silberkornern wahrend uber dem Dendriten zahlreiche SK liegen Die gleiche Beobachtung machten Oehlert Schultze &

und Entfernung des Stapes wurde das Labyrinth zur Fixierung in kaltes 6%iges Formalin mit 5% Trichloressigsäurezusatz eingelegt. Da es sich um junge Tiere handelte, bewirkte der Trichloressigsäurezusatz in 2–3 Tagen gleichzeitig eine ausreichende Entkalkung des Labyrinthknochens. Dem Fixierungsmittel wurde inaktives Leucin bzw. Lysin zugesetzt, um adsorbierte markierte AS auszutauschen. Um eine gute Durchdringung des Präparates mit dem Einbettungsmittel zu ermöglichen, wurde die Schnecke im Bereich des runden Fensters breit eröffnet. Nach Durchlaufen der Alkoholreihe wurde die Cochlea im Vakuum in Paraffin eingebettet.

2. *Autoradiographische Technik*

Für die Autoradiogramme (ARG) wurden 5 μ dicke Längsschnitte der Cochlea verwandt, von denen die den Modiolus treffenden ausgewählt wurden. Ein Teil der Autoradiogramme wurde nach der stripping film-Technik (Pelc 1947; Boyd 1947) mit Kodak AR10 hergestellt und 2–6 Wochen exponiert. Zusätzlich wurden Präparate mit der flüssigen Emulsion Ilford G5 hergestellt. Hierbei genügten Expositionsdauern von 3–20 Tagen. Nach photographischer Entwicklung wurde ein Teil der Schnitte durch die Photoschicht hindurch mit Hämatoxylin-Eosin gefärbt. Weitere Einzelheiten der Technik bei Maurer (1959), dort weitere Literatur.

Da die maximale Reichweite von Tritium 0,5 mg/cm² oder 5 μ in nassem Gewebe beträgt, die überwiegende Mehrzahl der emittierten β-Teilchen aber eine noch wesentlich kleinere Reichweite haben, erreicht man bei Verwendung dieses Isotops im Autoradiogramm eine fast punktförmige Abbildung. Das autoradiographische Auflösungsvermögen bei Anwendung von Tritium beträgt etwa 2/3 μ (vgl. Meyer zum Gottesberge 1961).

3. *Quantitative Auswertung durch Silberkornzählung*

Durch Auszählung der Silberkörner pro μ^2 Gewebefläche ist ein quantitativer Vergleich des AS-Einbaues in den einzelnen Geweben und Zellen möglich. Zur Auszählung wurden Okularnetzmikrometer verwandt, wobei ein Einzelquadrat bei Ölimmersion einer Fläche von 16 μ^2 entsprach.

Pro Zellart bzw. pro Gewebe wurde für jede der verwandten Aminosäuren jeweils 70–100 Einzelquadrate ($\approx$1120–1600 μ^2) ausgezählt. Sofern Zählungen nicht ausdrücklich an Zwischensubstanzen erfolgten, wurde so vorgegangen, daß wenigstens 50 Einzelzellen erfaßt wurden. Die Summen aller pro Zell- oder Gewebeart festgestellten Silberkornzahlen liegen zwischen 1000 und 3000. Der statistische Fehler der mittleren Silberkornzahlen pro μ^2 in Tabelle 1 bewegt sich also zwischen 1,8 und 3,1 Prozent.

Der subjektive Zählfehler konnte durch mehrmaliges Auszählen gleicher Areale insbesondere auch durch Kontrollpersonen bestimmt werden. Bei einem Zählergebnis von durchschnittlich 20–40 SK pro Zählquadrat war er immer kleiner als 10%.

Abb 3 Autoradiogramm des Ligamentum spirale des Meerschweinchens, 2 Std nach Gabe von H 3 Leucin Starke Schwärzung über der Stria vascularis, ebenfalls starke Schwärzung über den Bindegewebezellen des Lig spirale und über den Zellen im Bereich der Prominentia spiralis weniger starke Schwärzung über dem Zwischengewebe des Lig spirale Keine Silberk[illegible] der Grundsubstanz des Labyrinthknochens Die Gefäße der Stria vascularis sowie das [illegible] prominens sind ausgespart 300 fache Vergrößerung, stripping film, HE Färbung

Das im Modiolus liegende lockere Bindegewebe, in dem die Arte[illegible] des Tractus spiralis arteriosus und venosus verlaufen und das in Abb 2 jeweils am rechten Bildrand angeschnitten wurde, ist auffallend dark ge-schwärzt Die Silberkorndichte (2 23 SK μ^2) ist fast so groß wie die der Ganglienzellen

Ligamentum spirale und Stria vascularis

Abb 3 zeigt ein gefärbtes ARG des Ligamentum spirale Die [illegible]-förmigen Bindegewebezellen haben eine viel stärkere Schw[illegible] (1 79 SK/μ^2) als das lockere Zwischengewebe (0 79 SK/μ^2)

Abb 4 gibt ein stärker vergrößertes Autoradiogramm der [illegible] wieder Engstrom, Sjöstrand & Spoendlin unterscheiden ein[illegible] [illegible]ularis [illegible]phile und eine untere chromophobe Schicht Letztere soll [illegible] [illegible] mesodermalen Ursprungs sein Diese Trennung läßt sich [illegible] [illegible] graphisch durchführen, da die chromophile Schicht [illegible] Dichte hat (chromophile Schicht 2 06 SK μ^2, chromophob[illegible] [illegible] SK/μ^2)

Abb. 1. Autoradiogramm des Ligamentum spirale eines Meerschweinchens 2 Std. nach Gabe von H 3-Leucin. Die stark geschwärzte Stria vascularis hebt sich deutlich vom Bindegewebe ab. 700fache Vergrößerung, stripping film, HE-Färbung

Die nach Engström und Mitarb. zwischen den beiden Schichten liegenden Kapillaren sind als helle Aussparungen innerhalb der geschwärzten Umgebung zu erkennen. Ein Unterschied in den Silberkornzahlen zwischen pigmenthaltigen und pigmentfreien Zellen ist nicht feststellbar.

Der Schnitt des Autoradiogramms in Abb. 3 enthält u. a. die Prominentia spiralis. In dem unterhalb der Prominentia spiralis gelegenen Bereich des Sulcus spiralis externus, in dem die von Iwata beschriebenen Wurzelepithelien und Wurzelstöcke liegen, treten in der unteren Windung gelegentlich etwas stärker geschwärzte Zellen auf.

Die Schwärzung des zum Perilymphraum der Scala vest. bzw. der Scala tymp. zugewandten Anteils des Ligamentum spirale oberhalb bzw. unterhalb des Ductus cochlearis entspricht etwa derjenigen der chromophoben Schicht der Stria vascularis.

Reißnersche Membran

Bei der Reißnerschen Membran lassen sich bindegewebiger und epithelialer Anteil im Autoradiogramm nicht trennen. Die Silberkorndichte der Reiß-

Abb. 5. Autoradiogramm des Cortischen Organs des Meerschweinchens 2 Std. nach Gabe von H 3-Leucin. Starke Schwärzung über den Boettcherschen Zellen, weniger starke über den Sinnes- und Stützzellen. 300fache Vergrößerung, stripping film, HE-Färbung

nerschen Membran (1,32 SK/μ^2) ist etwas mehr als halb so groß wie die der Ganglienzellen.

Cortisches Organ

Abb. 5 zeigt ein Cortisches Organ aus der Basalwindung. Zur besseren Differenzierung der einzelnen Zellarten wurde der Schnitt mit Hämatoxylin-Eosin gefärbt. Als Folge der Besonderheiten dieses Gewebes (schmale Gewebebrücken von unterschiedlicher Konsistenz und daher unterschiedlicher Höhe, dazwischen optisch leere Räume) liegen die Silberkörner bei der hier gewählten Vergrößerung teilweise in verschiedenen optischen Ebenen. Dadurch können auf photographischen Reproduktionen von Autoradiogrammen mit starker Vergrößerung infolge geringer Tiefenschärfe Unterschiede in der Silberkorndichte vorgetäuscht werden. Der Unterschied in der SK-Dichte zwischen dem basalen und apikalen Anteil der äußeren Haarzellen ist nur scheinbar und durch die Grenzen der Reproduktion bestimmt.

Nach Tabelle 1 haben Haarzellen, Deitersche und Hensensche Zellen, ferner die Zellen der tympanalen Belegschicht etwa die gleiche Silberkorndichte. Über dem Innen- und Außenpfeiler liegen nur ganz vereinzelt Silberkörner. Die Lamina basilaris ist ganz frei von SK. Auffallend stark ist die Schwärzung über den stark basophilen Boettcherschen Zellen (2,03 SK/μ^2), die als kleine Zellinsel rechts von der Bildmitte unterhalb der Claudiusschen Zellen liegen.

Limbus spiralis und Membrana tectoria

Abb. 6 zeigt ein Autoradiogramm des Limbus spiralis. Über der Membrana tectoria am oberen Bildrand finden sich praktisch keine Silberkörner. Sie

Tabelle 1

Vergleich der Größe der Einbauraten von H 3 Leucin und H 3 Lysin in verschiedene Gewebe und Zellarten der Cochlea des Meerschweinchens anhand von Silberkorndichten. Die angegebenen Silberkorndichten in Silberkörner/μ² sind Mittelwerte über eine Gesamtfläche von jeweils 560 μ² oder mehr. Die für ein Tier angegebenen Werte entstammen ein und demselben Autoradiogramm und sind daher unmittelbar untereinander vergleichbar. Unterschiede in den absoluten Werten von Tier zu Tier hängen mit der Dosierung der Radioaktivität und der autoradiographischen Belichtungszeit zusammen.

	Meerschweinchen 89		Meerschweinchen 9[illegible]	
	H 3 Leucin Einbau		H 3 Lysin Einbau	
Zellart bzw. Gewebe	Silberkörner pro μ^2	Relative Einbaurate Ganglien zellen = 100	Silberkörner pro μ^2	Relative Einbaurate Ganglien zellen = 100
Ganglienzellen des Ggl. spirale	2.46	= 100	0.89	= 100
Stria vascularis	1.77	72	0.63	71
Chromophile Schicht d. Stria vascularis	2.00	81	0.72	81
Chromophobe Schicht d. Stria vascularis	1.51	61	0.53	59
Bindegewebezellen d. Ligamentum spir.	1.79	72	0.56	63
Zwischengewebe d. Ligamentum spir.	0.79	32	0.35	39
Haarzellen des Cortischen Organs	1.31	53	0.48	54
Stütz- und Pfeilerzellen d. Cortischen Organs	1.25	51	0.44	49
Reißnersche Membran	1.32	54	0.46	52
Claudiussche Zellen	1.04	42	0.38	43
Boettchersche Zellen	2.03	83	0.71	80
Epithel d. Limbus spiralis	0.84	34	0.32	36
Bindegewebezellen d. Limbus spiralis	1.18	48	0.45	51
Tympanale Belegschicht	1.30	53	0.50	56
Gewebe des medialen Bodens d. Scala vestibuli	1.44	58	0.53	59
Gefäßbindegewebe im Modiolus	2.23	91	0.82	92
Kerne der Schwannschen Zellen im N. cochlearis	1.37	56	0.43	48
Fasern d. N. cochlearis	0.44	18	0.20	22
Osteocyten d. Modiolus	1.05	43	0.35	40
Osteocyten der Labyrinthkapsel	0.90	37	0.36	40
Äußeres Periost der Labyrinthkapsel	1.63	66	0.51	57

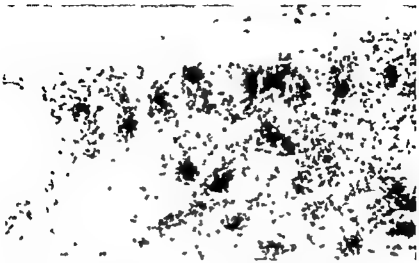

Abb. 6. Autoradiogramm des Limbus spiralis eines Meerschweinchens 2 Std. nach Gabe von H-3-Leucin. Zahlreiche Silberkörner über den Epithelzellen sowie über dem Bindegewebe. Keine Silberkörner über der Membrana tectoria. 700fache Vergrößerung. stripping film. HE-Färbung

hebt sich nur durch die Färbung von dem darunterliegenden Epithel einerseits und vom Lumen des Ductus cochlearis andererseits ab. Die Silberkorndichte über der Reihe der Epithelzellen des Limbus spiralis (0,84 Sk/μ^2) ist geringer als diejenige des Cortischen Organs. Demgegenüber sind die unter dem Epithel gelegenen Bindegewebezellen stärker geschwärzt (1,18 Sk/μ^2). Bei den schwächeren Vergrößerungen in Abb. 2 kommt der Schwärzungsunterschied zwischen Epithelzellen und Bindegewebezellen des Limbus spiralis gut zum Ausdruck.

Das in Abb. 2 oberhalb und medial vom Limbus spiralis gelegene, der Lamina spiralis ossea aufliegende Gewebe (Übergang vom rechten zum mittleren Bilddrittel), das den medialen Teil des Bodens der Scala vestibuli ausmacht, zeigt eine relativ starke Schwärzung (1,44 Sk/μ^2).

II. ERGEBNISSE MIT H-3-LYSIN

Abb. 2 zeigt zwei Autoradiogramme vom Ductus cochlearis nach Gabe verschiedener AS, und zwar Abb. 2*a* nach Gabe von H-3-Leucin und Abb. 2*b* nach Gabe von H-3-Lysin. Die Schwärzungsverteilung ist offenbar trotz Verwendung verschiedener AS die gleiche.

In den Spalten 2 und 4 der Tabelle 1 sind Silberkorndichten über den einzelnen Zellen und Geweben für H-3-Leucin und H-3-Lysin aufgeführt. Die Spalten 3 und 5 enthalten die relativen Einbaugrößen für die beiden Aminosäuren, wobei die für Ganglienzellen gefundenen Werte jeweils = 100 gesetzt wurden. Wie ein Vergleich der Spalten anzeigt, sind die relativen Einbauraten für alle untersuchten Gewebe und Zellarten etwa gleich.

Da die Autoradiogramme nach Verwendung von H^3-Leucin und H^3-Lysin keine Unterschiede in der Schwärzungsverteilung aufweisen, erübrigt sich eine Beschreibung der Ergebnisse nach Gabe von H^3-Lysin, weil sie lediglich eine Wiederholung der H^3-Leucin-Ergebnisse wäre.

BESPRECHUNG DER ERGEBNISSE

1. *Zur Frage des Zusammenhanges zwischen autoradiographischer Schwärzung und Aminosäure-Umsatzrate*

Nach Untersuchungen von Niklas & Oehlert (1956) und Oehlert, Schultze & Maurer (1958) kann als gesichert angenommen werden, daß die im Schnitt nachweisbare Radioaktivität auf peptidartig in Gewebeeiweiße eingebauten Aminosäuren beruht. Wenn die Versuchsdauer nur wenige Stunden beträgt, so daß ein Wiederabbau von Eiweiß noch vernachlässigt werden kann, gibt die eiweißgebundene Radioaktivität Aufschluß über die Umsatzrate der verwandten Aminosäuren (Maurer 1959).

Die relative autoradiographische Schwärzungsverteilung als Ausdruck der eiweißgebundenen Radioaktivität ist jedoch nur dann ein für alle Gewebe in gleicher Weise geltendes Maß der lokalen Aminosäureumsatzraten, wenn die mittlere spezifische Aktivität des Vorläufers an allen Gewebsorten gleich ist. Bei dem mit Vorläufer bezeichneten Komplex handelt es sich um die sogenannte „aktivierte Aminosäure" (lösl. RNS + Aminosäure). Da diese aktivierte Aminosäure wahrscheinlich nur eine sehr kurze Lebensdauer hat und deshalb schon kurze Zeit nach Gabe einer radioaktiv markierten Aminosäure im Isotopengleichgewicht mit der freien markierten Aminosäure steht, ist die spezifische Aktivität des Vorläufers praktisch zu jeder Zeit mit derjenigen der freien Aminosäure identisch. Damit ist die spezifische Aktivität des Vorläufers im wesentlichen abhängig von der Durchblutungsgröße bzw. von der Größe des Stofftransportes in den jeweiligen Geweben.

In gleichmäßig gut durchbluteten Geweben, wie Leber, Niere, Darm etc., ist die spezifische Aktivität der freien Aminosäure nach Niklas und Mitarb. (1958) schon wenige Minuten nach der Injektion gleich. Für die Gewebe der Cochlea ist dies allerdings nach Meyer zum Gottesberge & Plester (1961) nach 5 Minuten z. B. noch nicht, nach 15 Minuten aber schon fast der Fall. Diese Untersuchungen zeigen, daß wenigstens für die ersten 15—20 Minuten die spezifische Aktivität des Vorläufers im Cortischen Organ und in der Reißnerschen Membran kleiner ist als im Ganglion spirale und in der Stria vascularis. Da die hier vorgelegten Ergebnisse jedoch auf einer Versuchsdauer von 2 Stunden beruhen, dürften die „wahren" Umsatzraten für Reißnersche Membran und Cortisches Organ nur unwesentlich über den hier angeführten Werten liegen.

2. Folgerungen aus dem Vergleich der Autoradiogramme mit verschiedenen Aminosäuren

Für die Cochlea konnte gezeigt werden, daß die verschiedenen Aminosäuren (H 3-Leucin, H 3-Lysin) zu identischen autoradiographischen Schwärzungsverteilungen führen. Dies gilt auch für andere Gewebe. Nach Gabe von S 35-Aminosäuren, C 14-Aminosäuren, H 3-Leucin und C 14-Lysin beobachteten Schultze, Oehlert & Maurer (1960) an zahlreichen anderen Organen, z. B. Gehirn, Leber, Gastrointestinaltrakt etc., Nover & Schultze (1960) am Auge und Koburg (1961) an Knochen- und Knorpelzellen genau das gleiche.

Diese Unabhängigkeit der Autoradiogramme von der Art der verwandten Aminosäure ist ein Hinweis darauf, daß es sich bei dem Einbau dieser markierten Aminosäuren um einen Aufbau und Abbau, d. h. um eine *de novo* Synthese von Eiweiß handelt. Eine Gleichheit der Autoradiogramme mit verschiedenen Aminosäuren ist in dem Maß zu erwarten, wie die relative Aminosäure-Zusammensetzung der Gewebeeiweiße und seiner Fraktionen ebenfalls gleich ist. Tatsächlich ist dies angenähert der Fall (Cremer & Fuhr), wenn man von Ausnahmen wie Haut (hoher Cystin-Gehalt) absieht.

3. Vergleich der Größe des Eiweißstoffwechsels der Cochlea mit dem anderer Gewebe, insbesondere des Auges und des ZNS

In Tabelle 2 wird die Größe des Eiweißstoffwechsels der verschiedenen Gewebe der Cochlea mit derjenigen anderer Organe (Niklas & Oehlert 1956, Nover & Schultze 1960, Koburg 1961 *a*) verglichen.

Der sehr hohe Eiweißstoffwechsel der Ganglienzellen des Ganglion spirale cochleae entspricht dem der Ganglienzellen des Gehirns und der Netzhaut des Auges.

Der nur wenig geringere Eiweißumsatz des Tractus spiralis arteriosus et venosus und der Stria vascularis weist auf eine Parallele zum Plexus chorioideus des Gehirns, zur Aderhaut und zum Corpus ciliare des Auges sowie zu den Gefäßendothelien hin. Bei den genannten Geweben handelt es sich um mesodermales Gewebe mit zahlreichen Gefäßen, das teilweise (Stria vascularis, Plexus und Ciliarkörper) mit einem Epithel versehen ist. Bei diesen mit einem Epithel versehenen Geweben hängt der hohe Eiweißumsatz möglicherweise mit einer Eiweißsekretion zusammen. Ob auch für den Tractus spiralis art. et ven. eine sekretorische Funktion angenommen werden muß oder ob die in gefäßreichen Geweben gehäuft anzutreffenden Zellen des RES ausreichen, um den hohen Eiweißstoffwechsel zu erklären, kann z. Zt. nicht entschieden werden. Überraschend groß ist der Eiweißstoffwechsel der Böttcherschen Zellen, deren Funktion noch ungeklärt ist.

Die Zellen des Cortischen Organs haben einen Eiweißstoffwechsel von mittlerer Größe. Sie sind mit der inneren Körnerschicht des Kleinhirns und der inneren Körnerschicht der Augennetzhaut (Nover & Schultze) zu ver-

TABELLE 2

Vergleich der Größe des Eiweißstoffwechsels der Zellen und Gewebe der Cochlea mit der anderer Zellen und Gewebe des Organismus, insbesondere mit vergleichbaren Geweben des Auges und des ZNS. Die Ganglienzellen des Ganglion spirale cochleae wurden durch Silberkornzählungen an die Ganglienzellen des ZNS und des Auges angeschlossen. Die Zellen und Gewebe des Innenohres sind dadurch mit den übrigen Geweben vergleichbar

Zellen und Gewebe der Cochlea Meerschweinchen	Relative Größe des Eiweißumsatzes Ganglienzellen = 100 gesetzt	Vergleichbare Zellen und Gewebe des übrigen Organismus Meerschweinchen Maus, Ratte, Kaninchen	Relative Größe des Eiweißumsatzes Ganglienzellen = 100 gesetzt
Ganglienzellen des Ggl. spirale cochleae	≈ 100	Ganglienzellen des ZNS und der Augennetzhaut	≈ 100
Gefäßbindegewebe im Bereich der Arkaden d. Tractus spiralis arteriosus u. venosus		Plexus chorioideus des ZNS, Corpus ciliare u. Aderhaut des Auges, Endothelien und Zellen des RES	
Stria vascularis und Bindegewebezellen im Lig. spirale	60–100	Eiweißsezernierende Zellen: Pankreas, Nebennierenrinde, Osteoblasten	60–100
Boettchersche Zellen			
Sinnes- und Stützzellen des Cortischen Organs		Innere Körnerschicht des Auges, Körnerschicht des Kleinhirns	
Reißnersche Membran, Limbus spiralis, tympanale Belegschicht, Claudiussche Zellen	30–60	Stratum germinativum der Haut, Basalzellschicht der Zunge, des Oesophagus, Zellen der Lieberkühnschen Krypten des Darms	30–60
Fasern des N. cochlearis, Membrana tectoria	0–30	Glia und Mark des ZNS, Muskulatur, Bindegewebe und Stützgewebe	0–30

gleichen. Nach neueren Untersuchungen von Koburg (1961 b) hat auch das Sinnesepithel des Gleichgewichtsorgans und der Nase einen relativ kleinen Eiweißumsatz, dessen Größe mit derjenigen der Haarzellen des Cortischen Organs übereinstimmt.

Der Eiweißstoffwechsel der Nervenfasern des N. cochlearis und der Membrana tectoria ist sehr klein und entspricht etwa dem von Glia und Mark des ZNS, vom Hornhautstroma des Auges und dem von Binde- und Stützgeweben.

4. Vergleich der autoradiographischen Untersuchungen mit anderen histochemischen Ergebnissen

Nach Caspersson (1950) und Brachet (1952) ist die Größe der Eiweißsynthese innerhalb eines Gewebes von der Menge der im Gewebe vorhandenen RNS abhängig. Für diesen Zusammenhang ergaben die autoradiographischen Untersuchungen von Niklas & Oehlert (1956), Ficq & Brachet (1956), Oehlert, Schultze & Maurer (1958, 1959) und Maurer (1959) weitere Hinweise. Schultze, Oehlert & Maurer (1961) konnten inzwischen autoradiographisch nachweisen, daß nicht nur die Menge der RNS, sondern auch deren Umsatz der Größe des Eiweißumsatzes parallel geht.

Nach Hamberger & Hydén (1945, 1949), Bélanger (1956) und Beck (1960) enthalten die Ganglienzellen des Ganglion spirale cochleae viel RNS. Nach Caspersson wäre also ein großer Eiweißstoffwechsel zu erwarten, was auch tatsächlich der Fall ist. Für die Stria vascularis, die nach Bélanger (1956) und Beck (1960) ebenfalls reich an RNS ist, konnte in gleicher Weise ein reger Eiweißstoffwechsel nachgewiesen werden. Dies gilt insbesondere für die chromophile Schicht. Die bereits von Guild (1927), Dohlmann & Ormerod (1960) sowie Portmann und Mitarb. (1960) ausgesprochene Annahme, daß die Endolymphe von der Stria vascularis produziert werde, wird durch die hier autoradiographisch ermittelte Größe des Eiweißumsatzes weiter gestützt.

Die oberhalb und unterhalb des Ductus cochlearis gelegenen, der Scala vestibuli bzw. der Scala tympani zugewandten Abschnitte des Ligamentum spirale zeigen nach den hier vorgelegten Untersuchungen einen Eiweißstoffwechsel, der dem der chromophoben Schicht der Stria vascularis vergleichbar ist. Graf & Poretti schreiben diesen Abschnitten des Ligamentum spirale die Produktion der Perilymphe zu. Diese Annahme ist mit den autoradiographischen Ergebnissen vereinbar.

Einen etwa gleich großen Eiweißumsatz wie die erwähnten Abschnitte des Ligamentum spirale hat das Gewebe des medialen Bodens der Scala vestibuli. Man konnte daher vermuten, daß auch dieser Gewebebereich an der Produktion der Perilymphe teilnimmt.

Erstaunlich groß ist der Eiweißstoffwechsel der großen sternförmigen Bindegewebszellen des Ligamentum spirale. Dies paßt sehr gut zu der starken Basophilie, d. h. dem hohen RNS-Gehalt dieser Zellen.

Vosteen lehnt auf Grund von fermenthistochemischen Untersuchungen eine Beteiligung der tieferen Schichten des Ligamentum spirale an der Endolymphproduktion ab. Die hier vorgelegten Ergebnisse zeigen jedoch, daß der Eiweißstoffwechsel dieser Zellen etwa 10mal größer ist, als der des entwicklungsgeschichtlich vergleichbaren Unterhautbindegewebes. Welche Schlüsse daraus auf die Funktion der Zellen des Ligamentum spirale gezogen werden können, ist vorerst unklar.

In den Untersuchungen von Vosteen (1956, 1957/58) zeigte das Gewebe des Ligamentum spirale im Bereich zwischen Prominentia spiralis und Ansatz der Basilarmembran, also im Sulcus spiralis externus, dem Bereich

der Wurzelepithelien und Wurzelstocke von Iwata (1925) einen besonders hohen Gehalt an Atmungsfermenten. Auch der Eiweißstoffwechsel kann gelegentlich bei den Zellen dieser Region etwas größer sein. Trotz dieser Beobachtung kann bis jetzt nicht entschieden werden, ob dieser Gewebebereich eine sekretorische (Shambaugh 1909) oder resorptive (Engström & Saxén 1937, Saxén 1948, 1951) Funktion ausübt.

Bei den Haarzellen des Cortischen Organs überrascht der relativ niedrige Eiweißstoffwechsel, insbesondere angesichts der Angaben über den RNS-*Gehalt (Belanger 1956, Beck 1960) und über den hohen Gehalt an Atmungsfermenten* (Vosteen 1956, 1957/58).

Von Dohlmann (1960) wird angenommen, daß die Haarzellen sich hinsichtlich der Entstehung des Reizfolgestromes mehr passiv verhalten, indem sie durch die mechanisch bedingte Bewegung oder Krümmung der Sinneshaare eine *Modulation* eines bestehenden »Batteriestromes« ermöglichen. Demnach lehnt Dohlmann in Anlehnung an v. Békésy (1954) eine biologische — im Gegensatz zur mechanischen — Funktion der Haarzellen bei der Entstehung des Reizfolgestromes ab. Mit einer solchen Vorstellung von der Entstehung der Hörempfindung wäre die Feststellung des rel. niedrigen Eiweißstoffwechsels vereinbar.

Nach Vosteen unterscheiden sich die einzelnen Zellarten des Cortischen Organs durch ihren *Gehalt* an Atmungsfermenten, wobei die Haarzellen einen sehr hohen Gehalt haben. Demgegenüber ist der Eiweiß*stoffwechsel* bei allen Zellen des Cortischen Organs von gleicher, aber nur mittlerer Größe.

Diese beiden Beobachtungen stehen nicht in Widerspruch zueinander, weil histochemische Methoden lediglich Aussagen zur Menge erlauben, während die quantitative Autoradiographie den Umsatz von Substanzen wiedergibt. Die Menge einer Substanz muß deren Umsatzrate keineswegs parallel gehen. Ein Ferment, das in großer Menge vorhanden ist, kann einen trägen Umsatz haben und andererseits kann eine kleine Fermentmenge einen sehr großen Umsatz aufweisen (vgl. Meyer zum Gottesberge 1961).

Bei den Ganglienzellen und der Stria vascularis steht dem hohen histo*chemisch nachweisbaren Gehalt an Fermenten ein ebenfalls großer* Eiweißstoffwechsel gegenüber. Daneben gibt es Gewebe (z. B. Haarzellen des Cortischen Organs, ferner Skelett- und Herzmuskel, Nierenrinde u. a.), bei denen hoher histochemischer Fermentgehalt mit kleinem oder mittlerem Eiweißstoffwechsel einhergeht. Wiederum andere Gewebe, z. B. die Bindegewebszellen des Ligamentum spirale, zeigen einen niedrigen histochemisch nachweisbaren Fermentgehalt, aber einen sehr hohen Eiweißstoffwechsel. Wie schon angedeutet wurde, gehören zur Gruppe der Gewebe mit mittlerem Eiweißstoffwechsel sowohl fermentarme Zellen wie die Deiterschen, die Hensenschen und Claudiusschen Zellen der tympanalen Belegschicht und die Zellen der Reißnerschen Membran als auch die fermentreichen Haarzellen des Cortischen Organs. Es ist eine offene Frage, ob die Größe des Eiweißstoffwechsels einer Zelle eine Aussage zu ihrer funktionellen Bedeutung, insbesondere zu ihrer mittelbaren oder unmittelbaren Bedeutung bei der Entstehung des

Reizfolgestromes erlaubt. Bei den Zellen der Reißnerschen Membran ist der rel. hohe Eiweißstoffwechsel vielleicht zur Aufrechterhaltung der Potentialdifferenz zwischen Endo- und Perilymphe erforderlich.

In der Membrana tectoria ist praktisch kein Eiweißstoffwechsel nachweisbar. Auch Belanger (1956) kam nach Gabe von S 35-Methionin zu der Feststellung, daß die Membrana tectoria keine Aminosäuren einbaut.

Demgegenüber fanden Belanger (1953) sowie Dohlmann & Ormerod (1960) an der Membrana tectoria einen regen Einbau von S 35-Sulfat. Die Autoren deuten dies als einen Umsatz von Mucopolysacchariden. Dohlmann (1960) schreibt auf Grund von Modellversuchen den Veränderungen an Mucopolysaccharidmolekülen eine wesentliche Bedeutung bei der Entstehung der Hörempfindung zu.

Bei der Membrana tectoria handelt es sich offenbar wie bei der ihr chemisch ähnlichen Knorpelgrundsubstanz um eine typische „bradytrophe" Zwischensubstanz. Sie scheint sehr ionenaktiv zu sein, hat aber nach den vorliegenden Versuchen keinen Eiweißstoffwechsel.

Herrn Prof. Dr. W. Maurer möchten wir auch an dieser Stelle für wertvolle Hilfe und Hinweise danken. Die Untersuchungen wurden unterstützt vom Bundesministerium für Atomkernergie und von der Deutschen Forschungsgemeinschaft.

ZUSAMMENFASSUNG

Der Eiweißstoffwechsel der Zellen und Gewebe der Cochlea des Meerschweinchens wurde autoradiographisch mit H 3-Leucin und H 3-Lysin untersucht.

Für beide markierten Aminosäuren wurde das gleiche Inkorporationsschema gefunden. Dieses entspricht offenbar der Größe des Eiweißstoffwechsels. Die Autoradiogramme wurden quantitativ durch Silberkornzählung ausgewertet. Die Ergebnisse zeigen, daß die Ganglienzellen des Ganglion spirale cochleae den größten Eiweißstoffwechsel haben. Nur wenig kleiner ist der Eiweißstoffwechsel der Boettcherschen Zellen, der Stria vascularis und der Bindegewebezellen des Ligamentum spirale. Der Eiweißumsatz der Zellen des Cortischen Organs, der Reißnerschen Membran, der tympanalen Belegschicht und des Limbus spiralis ist von mittlerer Größe. Keinen Eiweißumsatz zeigt die Membrana tectoria.

Die für die einzelnen Zellen und Gewebe ermittelten Eiweißumsatzraten werden mit denjenigen anderer Organe, insbesondere denen der Sinnesorgane und des ZNS verglichen und im Hinblick auf die bereits bekannten Funktionen besprochen.

In Übereinstimmung mit den Vorstellungen von Caspersson und Brachet fand sich eine Parallele zwischen dem Ribonukleinsäuregehalt der Zellen und der Größe ihres Eiweißstoffwechsels.

SUMMARY

Protein metabolism of cochlear tissues was investigated in guinea pigs by means of autoradiographs with H 3-leucine and H 3-lysine. The incorporation pattern, i.e. the relative autoradiographic blackening distribution of both amino acids, was found to be equal, thus suggesting that the incorporation pattern of those precursors reflects

der Wurzelepithelien und Wurzelstocke von Iwata (1925) einen besonders hohen Gehalt an Atmungsfermenten. Auch der Eiweißstoffwechsel kann gelegentlich bei den Zellen dieser Region etwas größer sein. Trotz dieser Beobachtung kann bis jetzt nicht entschieden werden, ob dieser Gewebebereich eine sekretorische (Shambaugh 1909) oder resorptive (Erandt & Saxen 1937, Saxen 1948, 1951) Funktion ausübt.

Bei den Haarzellen des Cortischen Organs überrascht der relativ niedrige Eiweißstoffwechsel, insbesondere angesichts der Angaben über den RNS-Gehalt (Belanger 1956, Beck 1960) und über den hohen Gehalt an Atmungsfermenten (Vosteen 1956, 1957/58).

Von Dohlmann (1960) wird angenommen, daß die Haarzellen sich hinsichtlich der Entstehung des Reizfolgestromes mehr passiv verhalten, indem sie durch die mechanisch bedingte Bewegung oder Krümmung der Sinneshaare eine *Modulation* eines bestehenden »Batteriestromes« ermöglichen. Demnach lehnt Dohlmann in Anlehnung an v. Bekesy (1954) eine biologische — im Gegensatz zur mechanischen — Funktion der Haarzellen bei der Entstehung des Reizfolgestromes ab. Mit einer solchen Vorstellung von der Entstehung der Horempfindung wäre die Feststellung des rel. niedrigen Eiweißstoffwechsels vereinbar.

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Moorenstr. 5, Düsseldorf

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SENSORINEURAL HEARING LOSS FOLLOWING STAPEDECTOMY[1]

HAROLD F. SCHUKNECHT
Boston 14, Mass., U.S.A.

From the Department of Otolaryngology, Massachusetts Eye and Ear Infirmary and the Harvard Medical School, Boston

Profound sensorineural hearing losses have occurred in 20 of 750 stapedectomies for an incidence of 2.66 %. Nineteen of the 20 losses can be related to surgical technique. Eleven of the losses are probably related to extensive drilling of bony growth, other factors being previous traumatic mobilization, hemorrhage and instrumental trauma.

Surgical exploration performed on five ears following sensorineural hearing losses after stapedectomy revealed in one an excessively long prosthesis and in four, fibrous tissue proliferation in the oval window and vestibule associated with resorption of the free graft. This reaction is identical with the serofibrinous type of labyrinthitis which is readily produced in animals by trauma or by creating a perilymphatic fistula in the oval or round window.

The five types of inner ear reaction to traumatic stapes surgery are: hydrops, hypotonic atrophy, acoustic trauma, serofibrinous labyrinthitis and suppurative labyrinthitis.

A set of human temporal bones acquired from a patient with otosclerosis revealed secondary atrophic changes in the membranous labyrinth. It is possible that these alterations create a fragility which predisposes the cochlea to surgical injury.

Most of the sensorineural hearing losses following stapedectomy appear related to surgical factors which probably can be controlled.

Sensorineural hearing loss following stapedectomy is a manifestation of irreversible morphological changes in the cochlea. The severity of the hearing losses range from mild high tone deafness to total loss of sound perception. Often some auditory function is preserved but discrimination is so poor that the ear is almost useless for communication. The patient reacts with great disappointment and often added to their grief is a distressing tinnitus.

Incidence

My experience is based on 750 stapedectomies performed from January 1959 to April 1961. The operative procedure consistedof removing the stapes bone and replacing it with an adipose graft from the earlobe and a steel wire strut (1). Severe sensorineural type hearing losses occurred in 20

[1] Supported in part by a grant from the Central Bureau of Research of the American Otological Society.

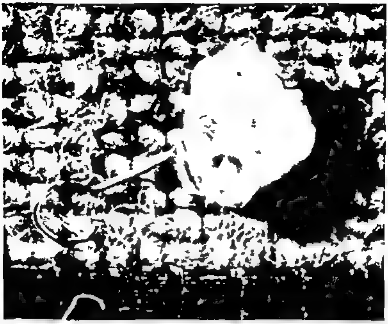

FIG 1A Sensorineural hearing loss developed 2 weeks after stapedectomy Surgical exploration performed [illegible] months later revealed a viable fat graft however the steel prosthesis had protruded through the graft to lie within the vestibule The hearing loss may be due to trauma from the prosthesis

(2 66%) of these 750 ears The onset of deafness was immediate in 11 and delayed in nine The length of time before onset of deafness in these nine ears was one to two weeks in six one month in one and six months in two An analysis of the records of these patients indicates that most of these failures were due to surgical factors which should be controllable In 11 of the 20 ears, extensive drilling was necessary to remove otosclerotic bone from the oval window Other probable factors were previous traumatic mobilization in three, excessive bleeding followed by hematotympanum in two and instrumental trauma to the membranous labyrinth in three In only one ear did hearing loss follow an uncomplicated operation

It seems unlikely that the metal implants were related to the sensorineural losses I performed 190 interpositions from October 1956 to January 1959 and 750 stapedectomies from January 1959 to April 1961 all with tantalum or steel prostheses and no extrusions meningitis or neoplasms have occurred Necrosis of the long process of the incus occurred in one ear

Findings at Re operation

Four of the 20 patients with sensorineural hearing loss following stapedectomy were subjected to re operation Case 1 experienced a sudden sensorineural hearing loss two weeks after an uncomplicated stapedectomy operation Exploration six months later revealed a viable adipose graft

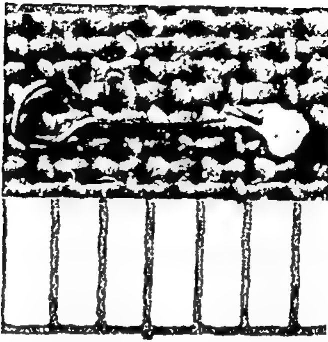

Fig. 1B. Sensorineural hearing loss developed immediately after stapedectomy with drilling. Surgical exploration performed 2 weeks later revealed partial resorption of the graft and proliferating connective tissue filling the oval window niche and extending into the vestibule (serofibrinous labyrinthitis). The photograph shows the prosthesis and partially resorbed graft.

However, the steel prosthesis was protruding through the graft into the vestibule (Fig. 1A). Because metallic implants into the vestibules of animals caused no reaction, it is probable that the hearing loss was due to trauma to the membranous labyrinth by the prosthesis and not due to the mere exposure of metal to the inner ear.

In cases 2, 3 and 4, extensive drilling with ½ mm cutting burrs was performed to remove otosclerotic bone from the oval windows. Deafness occurred immediately in two and, after one week, in one. An exploratory operation was performed in each about two weeks after stapedectomy. In all three, there were soft tissue masses in the oval window niche extending into the vestibules with partial resorption of the adipose grafts (Fig. 1B). There was no evidence of infection. The tissue consisted of proliferating fibrous tissue with a vascular stroma infiltrated with a few round cells and polymorphonuclear leukocytes. Some areas contained macrophages with fat droplets and in other areas there were intact fat cells (Fig. 2).

Dr. Joseph Sataloff gave me a similar tissue specimen which he had removed at re-operation from a patient on whom he had performed an extensive "drill out" procedure followed by a gelfoam plug and polyethylene prosthesis. A profound hearing loss occurred one week later. The exploratory operation was performed nine months later. He found the prosthesis in normal position and a soft tissue mass in the oval window extending into the

F[illegible] Sensorineural hearing loss occurred [illegible] immediately after stapedectomy with drilling. Surgical exploration was performed [illegible] weeks later in one patient (specimen A) and [illegible] weeks later in the other (specimen B). Both [illegible] partial resorption of the grafts and proliferating connective tissue filling the oval [illegible] and extending into the vestibules (serofibrinous labyrinthitis). Islands of fatty connective tissue remained (arrows).

Fig. 3. Sensorineural hearing loss was observed 1 week after stapedectomy and introduction of a gelfoam plug and polyethylene tube. An exploratory operation was performed 9 months later and revealed the prosthesis to be in normal position and a soft tissue mass in the oval window extending into the vestibule. The specimen consists of unresorbed gelfoam infiltrated by a network of loose areolar connective tissue covered on one side by a thin membrane. (Courtesy of Dr. Joseph Sataloff.)

vestibule. Examination of the tissue shows unresorbed gelfoam supported by a network of areolar connective tissue covered on one side by a thin membrane of endothelial-like cells (Fig. 3). The findings in these four patients are consistent with serofibrinous labyrinthitis which has been experimentally induced in animals.

Types of Surgically Induced Inner Ear Reaction in Animals

During the past four years, stapes surgery has been performed on 64 cat ears for the purpose of studying inner ear reactions and reparative processes. These procedures are not comparable with uncomplicated stapes operations in human beings, for they were often performed to provoke labyrinthine reactions. The operations consisted of stapes fractures, stapedectomies and free grafting, creating footplate fistulas, introducing metal protheses into the vestibule, and the instillation of blood or cerebrospinal fluid into the vestibule. Five different types of inner ear reactions could be identified. In some ears more than one type of reaction was evident, for example, mild hydrops and acoustic trauma. Dr. Albert Hohman is reporting these findings in detail elsewhere (2).

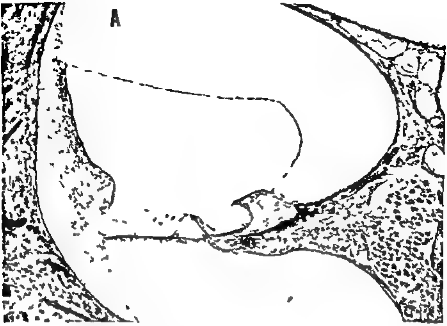

FIG. 4A. Photomicrograph of the cochlea of a cat in which stapedectomy was performed followed by instillation of blood into the vestibule and introduction of a gelfoam plug. There is a mild hydrops involving all three turns of the cochlea most evident in the apical turn.

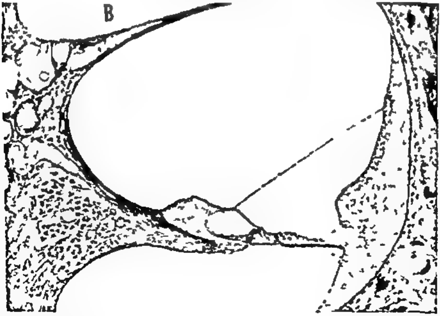

FIG. 4B. Photomicrograph of the cochlea of the opposite ear of the same cat in which an identical operative procedure was performed except that cerebrospinal fluid was instilled into the vestibule. The inner-ear reaction appears to be the direct opposite to that seen in A, that is, shrinking of all of the structures of the cochlear duct. This we have termed hypotonic atrophy.

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F u 6B I h tom rograph of a cat cochlea howing in a on f the scala vestibul ith connec ti e ti sue 2½ onths after stape lectom an l fat graft ser f t rinous l byrinthit)

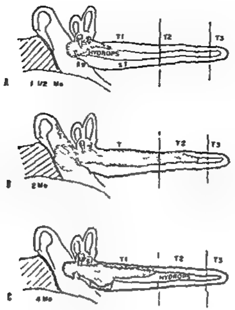


Fig 7 Diagrammatic reconstruction of three degrees of serofibrinous labyrinthitis after stapedectomy and grafting in three cats

peared in about 20% of stapes fracture but did not occur in ears in which an uncomplicated stapedectomy and graft procedure was done (Fig 5)

Serofibrinous labyrinthitis

Zange (4) and Steurer (5) demonstrated 40 years ago that opening the round window (without grafting) frequently resulted in invasion of the scala vestibuli with proliferating connective tissue and degeneration of the membranous labyrinth Because the earliest reaction was a serofibrinous exudate subsequently replaced by connective tissue, the term 'serofibrinous labyrinthitis' was used to distinguish the reaction from noninflammatory lesions

This reaction occurred in eight (12%) of the 64 stapes operations The severity of the reaction varied from mild invasion of the vestibule to extension into the scala vestibuli of the first, second and even third turns of the cochlea (Figs 6 and 7) Mild degrees of the reaction occurred in animals in which the soft tissue graft of the oval window was only partly effective in closing the opening thereby leaving a small fistula The basilar membrane appeared to act as a barrier against invasion from the scala vestibuli to the scala tympani In all cases there were advanced degenerative changes in the organ of Corti and an associated endolymphatic hydrops

Suppurative labyrinthitis

This reaction can result from surgery performed in the presence of middle ear infection or from subsequent middle ear suppuration in the presence of an

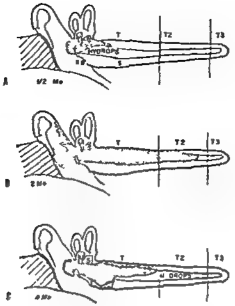
Fig 8 Suppurative otitis media labyrinthitis and meningitis in a cat occurring 5 months a[fter] creation of a stapes fracture and footplate fistula

oval window fistula This occurred in two of the 64 animals and in both [in]stances occurred in ears with fistulas of the footplate (Fig 8)

The Fragile Labyrinth

Occasionally an otosclerotic focus in the otic capsule extends through t[he] endosteal layer of bone to come in contact with the membranous labyrin[th] particularly the spiral ligament In these ears there may be second[ary] atrophic changes in the membranous labyrinth These pathological chan[ges] are well demonstrated in a set of human temporal bones acquired by [Dr.] Jaime Benitez at the Henry Ford Hospital The specimens are well preserv[ed] as a result of injection of formalin into the middle ears 20 minutes after dea[th]

The patient was 53 years of age and had experienced a slowly progress[ive] hearing loss for 30 years Audiometry revealed a combined (conductive a[nd] sensorineural) hearing loss in the left ear and total loss of hearing in the ri[ght] ear The patient did not recall whether the hearing loss on the right came suddenly or gradually nor did he know when the hearing loss in that e[ar] became severe He did state that he had not been able to use a hearing aid [in] that ear for many years



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Histological examination revealed large otosclerotic lesions involving the stapes margins of the oval windows and the lateral aspects of the cochlear capsules (Fig. 9). The lesions of the cochlear capsules extended to the endosteum and created severe atrophic changes in the spiral ligaments. The profound deafness in the right ear was the result of rupture to the basilar membrane which probably was secondary to shrinking of the spiral ligament. A more detailed report of these findings will be published elsewhere (6). Because these atrophic changes can lead to spontaneous rupture of the basilar membrane, it is entirely possible that there are lesser stages of atrophy when the labyrinth is fragile and easily injured by surgery. Therefore, when operating on ears with combined type deafness, it may be important to avoid sudden massive movements of perilymph which would agitate the cochlear duct.

ZUSAMMENFASSUNG

Weitgehender Verlust der neurosensorischen Hörfähigkeit stellte sich in 20 von 750 Stapedektomien ein, also mit einer Häufigkeit von 2.66 %. Neunzehn von 20 dieser Defekte können auf die chirurgische Technik zurückgeführt werden. Elf der Defekte wurden vermutlich durch zu weitgehendes Wegbohren von knöchernen Auswüchsen verursacht, andere Faktoren sind in traumatischer Mobilisierung, Blutung und instrumentellem Trauma zu suchen.

Bei chirurgischen Explorationen, die 5 Jahre nach Verlust der neurosensorischen Hörfähigkeit im Anschluss an Stapedektomie vorgenommen wurden, wurde in einem Fall eine besonders lange Prothese angetroffen, in 4 Fällen Proliferation von fibrösem Gewebe im ovalen Fenster und im Vestibulum zusammen mit Resorption des freien Transplantates. Diese Reaktion ist identisch mit dem serofibrinösen Typ der Labyrinthitis, den man bei Versuchstieren leicht produzieren kann durch Trauma oder eine perilymphatische Fistel im ovalen oder runden Fenster.

Die fünf Reaktionstypen des Innenohres auf Traumen bei chirurgischen Eingriffen am Stapes sind: Hydrops, hypotonie, Atrophie, Hörschädigung, serofibrinöse und eitrige Labyrinthitis.

Die Schläfenbeine eines Patienten mit Otosklerose liessen sekundäre atrophische Veränderungen im häutigen Labyrinth erkennen. Es ist möglich, dass durch diese Veränderungen eine Zerbrechlichkeit zustandekommt, welche die Cochlea für chirurgische Schädigungen anfällig macht.

Die meisten Fälle mit Verlust der neurosensorischen Hörfähigkeit nach Stapedektomie scheinen somit auf chirurgische Schädigungen zurückzuführen sein, welche vermutlich vermieden werden können.

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Massachusetts Eye & Ear Infirmary, 243 Charles Street, Boston 14, Mass, U S A

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AROUSAL EFFECTS AND NYSTAGMUS DURING PROLONGED CONSTANT ANGULAR ACCELERATION

W. E. Collins and F. E. Guedry, Jr
Oklahoma City, Oklahoma, U.S.A.

From the Psychology Branch, Civil Aeromedical Research Institute, F.A.A., Oklahoma City, Oklahoma, and Research Department, USN School of Aviation Medicine, Pensacola, Florida

Six subjects were given a series of 10 rotary trials in which accelerations of 1.0°/sec² and 1.8°/sec² were employed for durations of 84 and 50 seconds respectively. Subjective states of arousal were manipulated by *instructions*. Duration and *slow phase velocity* of nystagmus were measured. Qualitative as well as quantitative differences were observed as a function of arousal level.

Results indicated (1) during mentally active states no decline of nystagmus was evident during stimulation nor was there an abrupt cessation of nystagmus accompanying stimulus termination; (2) during states of mental relaxation the nystagmic response was reduced, declines during stimulation appeared, and the response occasionally ended prior to or at the moment of stimulus termination.

Theoretical implications of the findings are discussed.

In the semicircular canals, the inertial effects of a prolonged constant angular acceleration are balanced eventually by the spring action and friction of the cupula-endolymph system. If the vestibular reaction faithfully reflects cupula displacement, then the reaction should approach a maximum in about thirty seconds (van Egmond, Groen & Jongkees 1949, Mayne 1950, Groen 1956) and continue with little increase and no decrease until the constant angular acceleration terminates. With the end of such acceleration, the reaction should decline rapidly at first and then more gradually, and finally terminate after a period of time approximately equal to that required to attain the near maximum response.

Several points of departure from these theoretical expectations have been noted. (1) The subjective aspect of the reaction increases as expected for about 30 seconds but thereafter declines and may even terminate while the angular acceleration is still maintained at a constant magnitude (Dodge 1923, Guedry & Ceran 1959, Ek, Jongkees & Klijn 1960). It has been reported that vestibular nystagmus may follow a similar course (Buys 1924, Mowrer 1935, Wendt 1950, Ek *et al.* 1960, Hood 1961), although contradictory

Study conducted while both authors were at the U.S. Army Medical Research Laboratory, Fort Knox, Kentucky. The technical assistance of Kenneth J. Call is gratefully acknowledged.

evidence is available (Aschan 1955, Guedry & Lauver 1961). (2) The primary vestibular reaction after a prolonged angular acceleration does not persist with the intensity or duration theoretically expected and this has been reported for subjective (Guedry & Beberman 1951, Guedry, Cramer & Koella 1958) and oculomotor (Aschan 1955) aspects of the response. Again, however, there is some controversy about the persistence of nystagmus (Guedry & Lauver 1961).

Perhaps a significant variable accounting for these differences in results was the arousal level occasioned by the various testing procedures (Collins 1962, Collins, Crampton & Posner, 1961, Collins, Guedry & Posner 1962, Guedry & Lauver 1961). For example, when continuous estimation (and frequent signalling) of subjective angular displacement was required while nystagmus was being recorded, only occasional individual records exhibited a decline in nystagmus comparable to the decline in subjective velocity (Guedry & Lauver 1961). These occasional examples may have resulted from a declining state of arousal on the part of the subject as the subjective reaction diminished.

The present experimental conditions were selected to determine whether this evanescent rise, decline, and abrupt cessation of vestibular nystagmus associated with prolonged angular acceleration can be controlled by the assignment of different mental tasks. Specifically, three tasks were selected: (1) one which would maintain mental effort independent of the magnitude of the subjective vestibular reaction, (2) one which would demand little mental effort and which would be influenced by a declining subjective vestibular reaction, (3) one which would produce a shift in mental activity during the course of vestibular stimulation.

Apparatus and procedure

The rotary apparatus consisted of a large turntable (Guedry & Kalter 1956) situated in a light proof room. The subject was seated with his head in the center of rotation. A biteboard positioned the head so that the horizontal semicircular canals were approximately in the plane of rotation.

Two electrodes, taped near the outer canthus of each eye, were used for recording the horizontal component of eye movements. An indifferent electrode was taped behind the left ear on the mastoid process. The amplifying and recording device was an Offner Type T Electroencephalograph. Horizontal components of eye movements and periods of acceleration and deceleration were recorded.

A trial consisted of clockwise rotation as follows: (1) 30 seconds at a constant velocity of 1 rpm, (2) an acceleration of either 1.0°/sec² for 84 sec or 1.8°/sec² for 50 sec, (3) 2 minutes of constant velocity at 15 rpm following the 1.0°/sec² stimulus or at 16 rpm following the 1.8°/sec² stimulus, (4) a deceleration of either 1.0°/sec² for 84 sec or 1.8°/sec² for 50 sec, (5) 1 minute at a constant velocity of 1 rpm.

Two sets of instructions were employed

(1) Attending to the sensation—subjects were instructed to attend carefully to the sensation of rotation and to give reports concerning their experiences at the conclusion of each trial

(2) Mental arithmetic—subjects were instructed to ignore the rotational environment and to do mental arithmetic problems as rapidly as continuously and as accurately as possible Subjects were given a constant divisor and a starting dividend and were required to divide each successive quotient by that divisor An auditory signal was given 15 seconds prior to acceleration as a starting point for the mental computations Answers were recorded at the conclusion of each trial

Prior to each trial 20° eye movement calibrations were obtained from each subject and used as conversion factors for the later data measurements Trials were conducted in complete darkness but subjects were instructed to keep their eyes open

Six subjects all with previous turntable experience received trials of 1 0°, 1 8° 1 8° 1 0°, and 1 0°/sec² in that order in each of two sessions held on consecutive days Rest periods of 3 4 minutes were allowed between trials For half of the subjects (KG MH and PZ) the first session consisted of four trials with the mental arithmetic task and a final trial in which the subject attended to the sensation of rotation until with 42 seconds of deceleration remaining an auditory signal alerted him to start work on an arithmetic problem The second session consisted of four trials wherein the subject attended to the sensations of rotation and a concluding trial in which he did mental arithmetic For the remaining three subjects (DN JC and WD) the attend to sensation session was first and the arithmetic session last

Nystagmus records were divided into 5 second intervals for the periods of stimulation (with the exception of the first 4 seconds of the 1 8° sec² stimulus) and into 2 second intervals following the termination of stimulation These intervals were marked off in either direction from the point of stimulus termination to avoid depicting any spurious response decline The first 4 trials on each testing day were scored the fifth trial was used simply to demonstrate certain changes in nystagmus with changes of instruction during the same testing session

Within intervals the accumulated vertical distances from the peak of each nystagmic beat to the slow phase base line of that beat were measured and translated into average eye velocity (deg/sec) by means of the calibration values The average response for each interval was calculated for the group of six subjects

Results

Group Data

Average response curves for the two stimulus magnitudes appear in Figs 1 and 2 The arithmetic (MA) trials show no clear evidence of a decline of response during the interval of stimulation for either stimulus level Hence

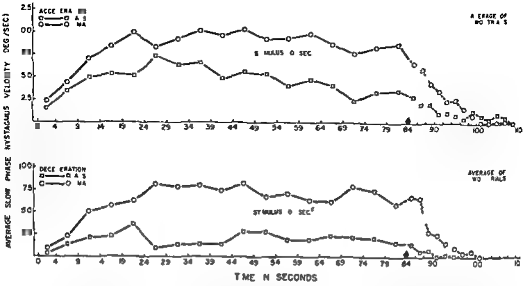

Fig. 1. Slow phase nystagmus velocity averaged for six subjects and two trials under conditions of mental arithmetic (MA) and attending to the sensation of rotation (ATS). Note the continuation of response (dotted line) after termination (marked by arrow) of 1.0°/sec² stimulus.

the nystagmus declines indicated by Ek *et al.* (1960) and by Hood (1961) are not confirmed under this condition.

Response to the "attend to sensation" (ATS) trials is markedly reduced in magnitude throughout the stimulus when compared to MA sessions. Nystagmic reactions to the 1.8°/sec² stimulus show no clear evidence of declining during the stimulus period. However, a decline appears in the 1.0°/sec² ATS trials during acceleration, and some decline is evident in the deceleration data after 20–30 seconds of constant angular acceleration, although the response output is low and inconsistent throughout the deceleration.

In both sets of curves, two other important features are apparent. First, the nystagmic response continues for a considerable period of time after the termination of stimulation (see Figs. 3 and 4). This is to be contrasted with Aschan's (1955) indication that nystagmus ends abruptly with the termination of acceleration when 1.0°/sec² stimuli are used. In no case did the response during an MA trial end prior to, or at the moment of, stimulus termination, nor was there any case in which no recorded response occurred to the stimuli. This was not true of the ATS sessions. Of the 48 ATS records obtained (considering accelerations and decelerations separately), 20 were scored as "zero response", and in 8 others the nystagmic response ended prior to, or at the moment of stimulus termination. A breakdown of the response duration appears in Table I.

Second, Aschan (1955) has reported that at higher accelerations (i.e. greater than 1.0°/sec²) a 50 per cent fall off in response occurs during the first second after stimulus termination. The MA trials do not show this rapid decline. On the average, a 50 per cent drop in slow phase nystagmus occurs only after 4–6 seconds with the two stimulus magnitudes used here.

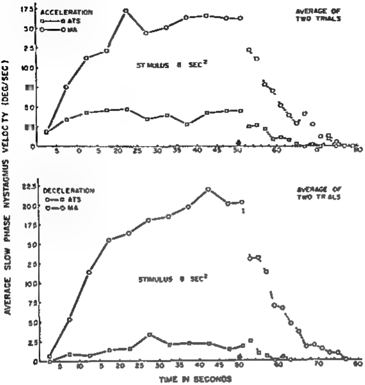

Fig. 2. Slow phase nystagmus velocity averaged for six subjects and two trials under conditions of mental arithmetic (MA) and attending to the sensation of rotation (ATS). Arrows indicate end of 1.8°/sec² stimulus.

However, examples of the effect reported by Aschan may be found in the ATS trials.

Individual Examples

All records where nystagmus was present were scored and plotted (slow phase velocity against time). Twenty ATS records where scored as "zero magnitude" response. Of these 11 were similar to the ATS record depicted in Fig. 4, i.e. there was no evidence of nystagmus. The remaining 9 records are typified by the ATS response in Fig. 5. Here fast phases of lower velocity than normal are evident as part of a low frequency, large amplitude nystagmus. Since this is not the usual nystagmic reaction to angular acceleration we have chosen to regard it as "zero response", but to make note of its occurrence. It should be noted that six of these nine unusual response records were obtained from one subject (MH).

The striking effect that instructions have upon the nystagmic response to angular stimulation is clearly depicted in Fig. 6. Here the subject attended to the rotary sensation (ATS) for the first half of a deceleration period until an auditory stimulus signalled him to begin work on an arithmetic problem (MA). The change in the character of the response is very striking and points

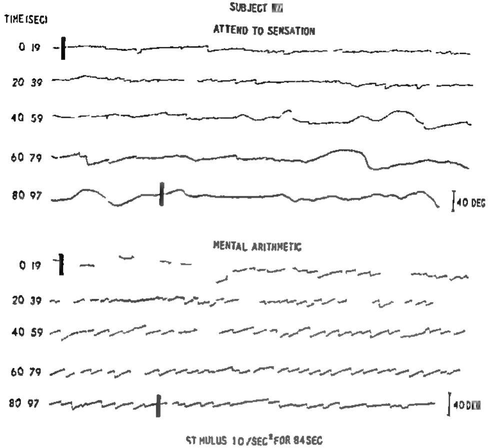

Fig 3 Examples of response to angular accelerations of 1 0°/sec² under conditions of mental arithmetic and attending to the sensation Vertical bars mark off periods of stimulation

up the importance of the alertness factor in maintaining a clear nystagmic reaction when vision is excluded

An additional subject (GB) who had demonstrated high output nystagmus in another study was used here for a single trial at 0 5°/sec² His response to 87 sec of acceleration while doing a division problem is presented in Fig 7 Even at this low magnitude of acceleration the nystagmic response continued beyond the termination of stimulation

Discussion of results

Several points have been clarified by this experiment

1 With stimuli of the magnitude used in this experiment inexperienced subjects will give a clear response to the first stimulus application However with subsequent runs as they are relaxed and less apprehensive about the situation the clear nystagmic reaction may completely disappear or may come and go as the individual per chance becomes mentally active Assignment of mental tasks which maintain alertness systematizes the nystagmic response to vestibular stimulation and avoids the problem of chance activa

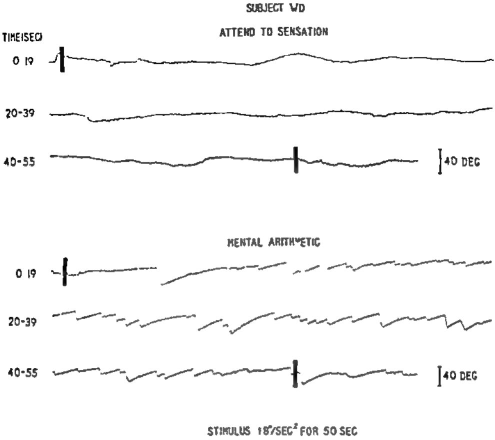

FIG. 4. Examples of response to angular accelerations of 1.8°/sec² under conditions of mental arithmetic and attending to the sensation. Vertical bars mark off periods of stimulation.

TABLE 1. *The prolongation of the nystagmic reaction after termination of stimuli of 1.0°/sec² (for 84 seconds) and 1.8°/sec² (for 50 seconds)*

The data are based upon six subjects tested twice under each condition

Condition		Zero Response	Prior	Seconds after stimulus termination 0	2	4	6	8	10	12	14	16	18	20	22	24	26	28
Attend to sensation																		
1.0°/sec²	Accel	[illegible]	3	0	1	2	0	1	0	1	0	0	1	0	0	1	0	0
	Decel	6	1	0	1	1	1	1	1	0	0	0	0	0	0	0	0	0
1.8°/sec²	Accel	4	2	1	0	1	1	1	0	0	0	1	0	0	0	1	0	0
	Decel	8	0	1	0	0	1	1	0	1	0	0	0	0	0	0	0	0
Mental arithmetic																		
1.0°/sec²	Accel	0	0	0	0	1	2	1	0	2	2	1	1	0	1	1	0	0
	Decel	0	0	0	2	1	1	3	2	1	0	2	0	0	0	0	0	0
1.8°/sec²	Accel	0	0	0	0	0	0	2	1	0	2	0	1	3	1	0	1	1
	Decel	0	0	0	0	0	0	0	1	0	1	1	3	2	1	1	2	0

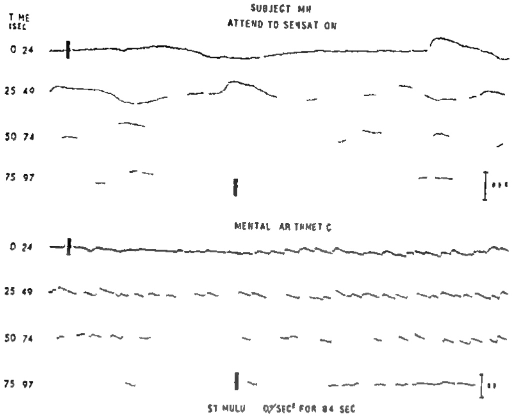

FIG. 5. Response of MH to angular deceleration of 1.0°/sec² under conditions of mental arithmetic and attending to the sensation of rotation. The large amplitude low frequency beats in the upper record were scored as zero nystagmus.

tion. It is therefore possible, by assigning tasks which control the subject's mental activity, to reduce variability attributable to arousal effects. Such procedures are feasible and probably permit more adequate assessment of the oculomotor and vestibular systems *per se* than would otherwise be possible.

2. The subjects of the present experiment all had previous turntable experience and were not apprehensive at the outset of the study. Simply attending to the sensation of rotation (ATS) in these experienced subjects was insufficient mental effort to activate a brisk, long duration vestibular nystagmus. Further, during ATS the nystagmic reaction declined, on the average, where previous experiments (Guedry & Ceran 1959) have indicated a declining subjective reaction. During mental arithmetic with 1.0°/sec² and 1.8°/sec² stimuli there were no examples of a loss or a clear decline in nystagmus.

3. Reduction of nystagmus in the ATS situation appears to be a loss of a clear fast phase of the nystagmus cycle and a decline in the frequency with which the fast phase repositioned the eyes to start a new beat. Often there was a nystagmus-like character to the eye movements. However, the beat

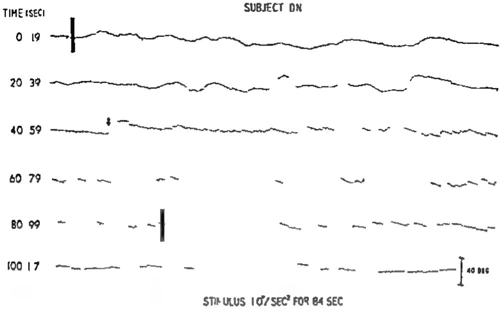

FIG. 6. Response of DN to angular deceleration of 1.0°/sec². For the first half of the stimulus period (vertical bars) the subject attended to the sensation of rotation, then, at a given signal (arrow), he began a mental arithmetic problem.

frequency was not as great, the fast phase and slow phase velocities were lower, and the transition from slow phase of one direction to fast phase of opposite direction was more gradual (so that the peaks were "rounded") than these same aspects of nystagmus during an alerted state. Occasionally there was no discernible difference between the slow phase and fast phase. In this case a slow, large amplitude, low frequency oscillation of the eyes was present. Seldom were the eyes fixed to a fairly constant position (interrupted only by occasional sharp movements of the eye, as though to new fixation points) as they were before stimulation commenced. Occasionally a low amplitude nystagmus of low slow phase velocity but with approximately normal fast phases appeared to be superimposed on this slow, large amplitude oscillation. Even where a sharp nystagmus was present, its slow phase velocity was, on the average, lower during ATS than MA.

4. Mental activity used in the present experiment apparently prevented the rapid cessation of nystagmus after stimulus termination that Aschan reported (1955). There were no examples of this in the present study during MA, although some occurred during ATS.

5. In this experiment, subjects' eyes were open in the dark. This also may account for some difference in results. It is likely that closing the eye lids influences arousal (Jasper, 1958) and it is known that the amplitude and duration of nystagmus, as recorded by the corneo-retinal method, declines with eye closure even though the subject is already in total darkness (e.g. Guedry & Montague, 1961).

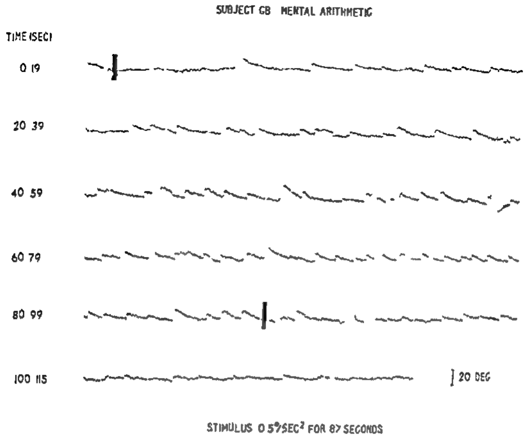

FIG 7 Response of a subject with high nystagmus output to a stimulus of 0 5°/sec² Vertical bars denote stimulus period Note the beats occurring after stimulus termination

GENERAL DISCUSSION

The loss of clear nystagmus during a sometimes adequate stimulus and its later return without renewed vestibular stimulation has been pointed out many times (Wendt, 1951, Bender, 1955, Guedry, Peacock & Cramer 1957, Mahoney, Harlan & Bickford, 1957, McLay, Madigan & Ormerod 1957, Lidvall, 1961) The general idea that something like alertness is important in maintaining nystagmus under certain conditions has been noted by the same authors and has received intensive investigation by others (Krieger & Bender, 1956, Duensing & Schaefer, 1957, Collins, 1962, Collins, Crampton & Posner, 1961, Collins, Guedry & Posner, 1962, Crampton & Schwam 1961, Guedry & Lauver, 1961)

In this experiment the loss of clear vestibular nystagmus during periods of mental relaxation occurred in several ways but the eyes were not simply displaced in the slow phase direction The fast phase was replaced by a slow phase in the anticipated fast phase direction or by a substantially reduced fast phase During such periods regardless of the speed of the fast phase the eye movements, in the anticipated slow phase direction, were of

lower velocity than during regular nystagmus when the subject was mentally active.¹ It may be that these several types of eye movements (reduced slow phase with fast phase normal, reduced slow and fast phase, slow oscillation with no distinguishable fast phase) represent different levels of alertness which influence differently the eye centering tendency discussed by Bender (1955). However, it is important to note that the slow phase tendency has also been reduced. Hence, the slow phase of nystagmus may vary with the fast phase when the nystagmus intensity is influenced by alertness as in the present work, or by the magnitude of the cupula deflection as in the work of Koike (1959). Apparently arousal is important to the maintenance of both slow and fast phases of nystagmus, but it is the fast phase which undergoes the most apparent change when activation varies.

On the Rise and Decline of Nystagmus During Constant Angular Acceleration

Lowenstein (1956) has indicated that as the cupula displacement is increased, neural activity is initiated in one after another previously silent units of higher threshold. These elements of higher threshold often adapt themselves rather rapidly and fire over a limited range of stimulus intensity, while the spontaneously firing elements are delicately poised to react to near threshold stimulation and are either non adapting or slowly adapting. This provides a peripheral basis for the previously noted decline of the subjective reaction during constant angular acceleration, leads to the expectation that nystagmus should also decline, and further suggests that higher magnitude stimuli (which may recruit a higher preponderance of the rapidly adapting units) may produce a more rapid rate of decline than lower magnitude stimuli. These latter expectations have not been substantiated by results obtained here or in previous experiments (Guedry & Lauver 1961). It is of course possible that in these several experiments none of the stimuli employed were of sufficient magnitude to recruit the rapidly adaptating units found by Lowenstein in the ray. Hence this peripheral adaptation may not account for any of the so called adaptation effects observed with low magnitude stimuli. As a matter of fact, only the subjective aspect of the vestibular reaction consistently has shown a rise and decline during constant angular acceleration.

In the experiment of Guedry & Lauver (1961) the subject was required to signal with telegraph key successive apparent 90 degree angular displacements throughout the subjective aspect of the vestibular reaction. In this case the task, which was sufficient to demonstrate the decline in the subjective reaction, served to maintain nystagmus. However, the maintenance of nystagmus was not attributable to the sensation or vertigo oriented state of the subject (the present results on ATS confirm this), but rather to the mental effort required by the continuous and difficult task of estimating an

¹ Although a time constant was present in the amplification system used herein, one of the authors has made similar observations during the recordings of eye movements under similar conditions (Guedry & Lauver 1961).

gular displacement plus the decision and act of pressing the response key (Jasper 1958) Probably the subjective decline is simply another manifestation of the mechanism which accounts for the different slopes of sensation and nystagmus cupulograms (Groen 1956) and the adaptation effects noted by Hallpike & Hood (1953) and others

The present experiment shows that when care is taken to keep the subject mentally active by a method not itself subject to decline as a result of the declining subjective reaction then nystagmus does not decline as an angular acceleration is maintained beyond 30 seconds neither does nystagmus terminate abruptly with the end of acceleration However when the subject attends casually to the sensation of rotation the nystagmus may decline during the angular acceleration and end before or shortly after the termination of stimulation These latter findings may be examples of indirect control of nystagmus by the subjective aspect of the vestibular reaction i e as the subjective reaction declines the subject may fortuitously lapse into a state of reduced mental activity which would in turn reduce vestibular nystagmus

However the control of the decline of nystagmus by the vestibular reaction may not be a fortuitous event but rather the normal course of events when extraneous sources of arousal are eliminated In most experimental situations during the course of a prolonged cupula deflection although the subjective reaction may decline there are many extraneous sources of mental activation which are not under experimental control Any of these might serve to reactivate nystagmus particularly while cupula initiated neural activity is still in progress Hence early in an experimental session while a subject is becoming familiar with the situation nystagmus may be maintained by any of these several arousal sources With prolonged or repeated exposure to the situation these various stimuli may lose their arousal value as demonstrated by Sharpless & Jasper (1956) for auditory stimuli In the present experiment an extraneous source of activation was purposely introduced (MA)

Perhaps without extraneous arousal the normal course of events is for nystagmus velocity and subjective velocity to rise attain a maximum at approximately the same rate (see e g Guedry Collins & Sheffey 1961 Guedry & Lauver 1961) and then follow a comparable decline The vestibular sensory data may be a source via the vestibular cortical projection area of feedback to the reticular formation which in turn modulates vestibular nystagmus Since it has been suggested that experienced sensation is dependent upon corticofugal impulses (Jasper 1958) loss of subjective velocity may be an indicator of reduced corticofugal feedback to the reticular system Hence as the subjective velocity declines during constant angular acceleration the nystagmus would decline except for extraneous sources of arousal These extraneous sources are legion other sensory stimuli which serve to alert the subject self determined control of mental states (for example see subject JW Fig 11 in Guedry Collins & Sheffey 1961) or self determined arousal capable of experimental control such as mental arithmetic tasks (Collins 1962 Collins Crampton & Posner 1961 Collins Guedry

& Posner, 1962) or difficult psychophysical judgments (Collins, 1962, Guedry & Lauver, 1961)

It is sometimes implied that loss of sensation without a concomitant loss of nystagmus suggests that no 'true adaptation' has occurred. It is perhaps more realistic to recognize that this subjective decline signals a physiological event and it is suggested that this decline would always be accompanied by a decline in the other facets of the vestibular reaction if it were possible to isolate the system from extraneous sources of activation. However these extraneous sources, when systematically introduced, can do much to maintain the level of vestibular nystagmus during prolonged cupula deflection.

ZUSAMMENFASSUNG

An 6 Personen wurde eine Reihe von 10 Rotationsversuchen vorgenommen, bei welchen Beschleunigungen von 1,0°/sec² und 1,8°/sec² während 84 bzw. 50 Sekunden zur Anwendung kamen. Durch Aufgaben (Anweisungen?) wurde ein subjektiver Zustand von psychischer Anspannung hervorgerufen. Die Dauer des Nystagmus und dessen Schnelligkeit während der langsamen Phase wurden gemessen. Sowohl qualitative wie quantitative Unterschiede als Funktion des Grades des Anspannung wurden beobachtet.

Ergebnis: 1. Im Zustand von geistiger Aktivität war weder eine Abnahme des Nystagmus während der Reizung sichtbar, noch trat bei Beendigung der Reizung ein abruptes Aufhören des Nystagmus ein. 2. Im Zustand von geistiger Entspannung war die Nystagmusreaktion vermindert, während der Reizung trat ein Absinken auf und die Reaktion endete gelegentlich vor oder im Augenblick der Reizung.

Die theoretische Bedeutung der Befunde wird besprochen.

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AM 907, CARI, FAA
Oklahoma City, Oklahoma

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FREQUENCY METER FOR NYSTAGMUS ANALYSIS

Nicholas Torok and Florian Nykiel
Chicago Ill USA

From the Department of Otolaryngology, University of Illinois College of Medicine Chicago

Vestibular testing aims to express vestibular sensitivity Sensory organ sensitivity has not one but several characteristics In addition to nystagmus duration the culmination of the nystagmus frequency during the reaction and the frequency pattern behavior is obtainable by means of nystagmography The above properties of the reactive or spontaneous vestibular nystagmus can be made readily accessible by the use of a simple frequency analyzer The computer signals all the nystagmic events in successive [illegible] sec time units Also directional preponderance and preponderance of frequency can be visualized automatically

The architecture of neuro otology is based upon the measurement and evaluation of cochlear and vestibular function For the assessment of cochlear sensitivity a battery of methods and tests is available Until recent years vestibular testing has been restricted to a limited field of observation This was the duration of the poststimulatory nystagmus Function and sensitivity have various characteristics As in the case of hearing a number of qualities of sensitivity are known such as frequency limitations threshold of intensity discrimination for speech recruitment fatigue etc It became evident that vestibular sensitivity could not be sufficiently characterized by a simple parameter of response to stimulation

More careful observation during the course of the reactive vestibular nystagmus elicited by whatever stimulation provides a series of informative and distinctive features of sensitivity Nystagmography however automatically rendered greatly improved observation

We attempt to summarize briefly the various forms and expressions of vestibular sensitivity as it may appear during the course of the nystagmus reaction

Fig 1 represents an average nystagmogram obtained following the cold thermic stimulation as we administer it routinely (10 cc water at 20 C applied with visual control in [illegible] sec time)

The same record can be better appreciated with a time scale superimposed on the curve Each single time mark is equivalent to [illegible] sec (Fig 2) The

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FIG 1 Thermic nystagmogram

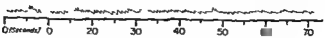

FIG 2 The same nystagmogram with time scale

frequency of the nystagmus activity can be analyzed by counting the number of eye beats per 5 sec time unit successively during the entire reaction The result of such an analysis may be expressed or recorded in two ways With a graph plotted on a coordinate system or even simpler by a series of numbers delineating the number of nystagmus beats during the successive 5 sec time units along the length of the reaction

The course of the same reactive nystagmus following a cold thermic stimulation may then appear as demonstrated in Fig 3 In the first 5 sec time period four nystagmus beats occurred The event plotted on the coordinate and/or a figure of 4 likewise expresses the intensity of nystagmus activity during this period The consecutive two 5 sec time units may be followed on the graph or on the figures indicating that the frequency of the vestibular nystagmus is increased At 20 sec after the beginning the nystagmus frequency apparently reached a maximum value and 10 sec later it is evident with absolute certainty that the nystagmus frequency had a culmination and then begins to decline In the remainder of the record the gradual decrease of frequency is quite evident on the graph and continues as the graph shows until the reaction ceases Fig 4 represents a similar tracing of an average rotatory response Such a course is observed under normal conditions The graph or the series of figures clearly demonstrates not only the duration but the intensity of this vestibular reflex reaction

In addition to the total duration two important items of information were obtained (1) the peak or culmination of the frequency expressed for the 10 sec period when the nystagmus was the most active (2) the typical

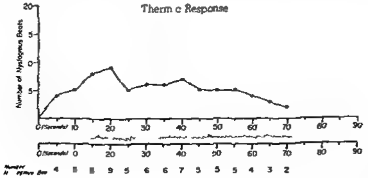

FIG 3 The same nystagmogram Frequency is plotted in graph (above) and in figures (below)

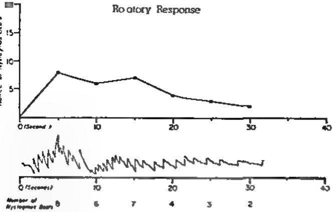

Fig 4 Postrotatory nystagmogram and frequency analysis in graphs and figures

pattern created by the behavior of the nystagmus frequency during the course of the reaction

Even by taking a glance at the graph of nystagmus frequency a striking resemblance appears between this and the contour of the recording of the eye speed, i e , the velocity of the slow component as proposed by Henriksson (Fig 5) It is assumed that the velocity of the slow phase of the nystagmus is determined and is proportional to the rate of deflection of the cupula in the ampullary end organ Comparative studies proved the great similarity of the two records, and simple logic can support the assumption that slow component velocity and frequency behavior have an identical origin

Because of the great resemblance which exists between eye speed and nystagmus frequency recordings, it is felt that the significant information provided by the recording of the slow component velocity can be omitted, as long as the frequency of the nystagmus is analyzed Technically, the latter proved to be a much easier process than the recording according to Henriksson

To analyze the conventional nystagmogram for frequency culmination and pattern is a simple procedure requiring but little time To simplify

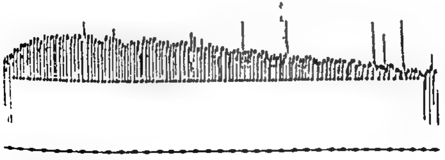

Fig 5 Eye speed recording carried out by Henriksson The contour of the graph is similar to the frequency plotting (Courtesy of Dr Nils G Henriksson)

Diagram of Simultaneous Recording of Nystagmus and Nystagmus Frequency

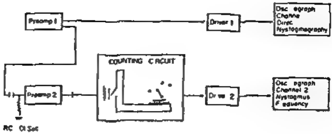

FIG 6

the recording and make frequency analysis easier, so as to have culmination and frequency pattern readings available at a glance, a frequency meter was employed A simple electronic device was constructed (Fig 6)

The counting circuit consists of a unistable multivibrator with a relay in the plate circuit of the tube This tube is normally turned off The switch in this relay closes momentarily each time a nystagmus occurs and a 110 V pulse is sent to the coils of a stepping relay The input to the multivibrator is the normal triangular shaped nystagmus wave form, obtained after filtering and clipping so that a positive sharp pulse remains A timer transmits a pulse to the reset coil of the stepping relay every five seconds At the same

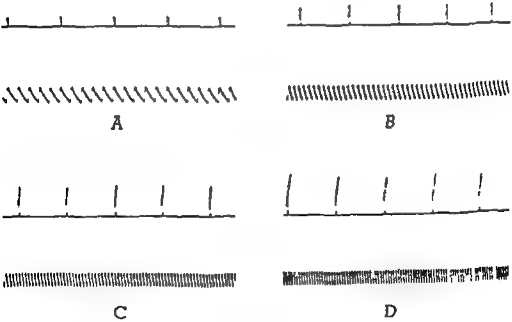

FIG 7 Simulated nystagmus Lower graphs are conventional recordings Upper graphs are computer signals corresponding to the number of nystagmus beats in 5 sec time units A 5/5 sec nystagmus frequency B 10/5 sec nystagmus frequency C 15/5 sec nystagmus frequency D 20/5 sec nystagmus frequency

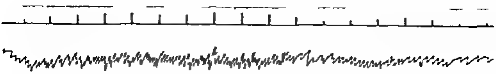

Fig 8 Thermic nystagmogram Conventional recording and simultaneous frequency meter signal series

time the circuit closes between the stepping switch and the input to the oscillograph driver In this way the oscillograph channel records a pulse that is proportional to the number of nystagmic movements in the previous 5 sec period Fig 7 is a record of simulated nystagmus beats of various frequencies Graph A demonstrates a frequency of 5 nystagmus beats per 5 sec, *graph B 10 beats per 5 sec, graph C 15 beats per 5 sec and finally* graph D 20 beats per 5 sec The length of the computer signals which is above the simulated nystagmogram corresponds to the number of nystagmus beats in 5 sec time units In graph A the computer signal is 5 mm long and rises by 1 mm to one additional nystagmus beat per 5 sec Accordingly above graph D a signal of 20 mm can be observed

The recording is carried out on at least two channels (Figs 8 and 9) The conventional nystagmogram is obtained on one and the computed frequency can be read immediately on the other If a slow paper speed is employed for the frequency computer, a very condensed and short record provides all the necessary data of the test

The vertical signals of the computer could be replaced by actual figures by incorporating a simple counter into the device The vestibular test result will then appear similar to a cash register slip with a series of figures exhibiting the length of the total reaction the culmination and frequency pattern

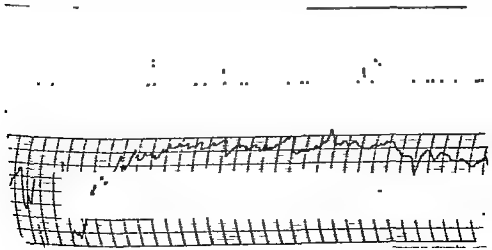

Fig 9 Postrotatory nystagmogram and computer analysis of frequency

Errors may be possible. The computer will count every horizontal eye deflection in one direction or the other. A voluntary eye motion may, therefore, also be counted. Such a disturbing effect can readily be detected on the conventional nystagmogram and subtracted from the frequency count. We hope to eliminate such occasional errors by further improving the computing device and recording technic.

To summarize, a simple computer attached to the nystagmographic equipment provides immediately a legible, simple and comprehensive record of vestibular sensitivity with accurate data of the duration, culmination of the frequency and the frequency pattern. This aid in recording can be applied to the testing of directional preponderance of duration, also for possible preponderance of frequency which may be simultaneously occurring or completely independent of the duration preponderance.

ZUSAMMENFASSUNG

Vestibularuntersuchungen erstreben die Beurteilung der vestibularen Sensitivitat auszudrucken. Sinnesorgan Empfindlichkeit hat nicht nur eine, sondern mehrere Merkmale oder Charaktereigenschaften. Mit der Hilfe des Nystagmographs, als Zusatz zur Dauer des Nystagmus, kann man den Gipfel bestimmen, oder die Kulmination der Nystagmus-Haufigkeit und schliesslich das Verhalten der Form der Nystagmusfrequenz wahrend der Reaktion. Die erwahnten Eigenschaften, zusammen mit Richtungs-Überlegenheit und Haufigkeitsbereitschaft, konnen durch Anwendung eines einfachen Frequenzmeters ausgedruckt werden, welche alle Nystagmusereignisse in Zeiteinheiten von 5 Sekunden bezeichnet.

University of Illinois, College of Medicine
Chicago, Ill., U.S.A.

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A HISTOLOGICAL INVESTIGATION OF THE AUDITORY PATHWAYS IN NEONATAL ASPHYXIA

A Preliminary Report

JENS G. HALL
Oslo, Norway

From the Anatomical Institute (Head: Prof. Jan Jansen, M.D.), Oslo

It appears from this preliminary report that there is a definite loss of cells in the cochlear nuclei of fatally asphyxiated children. The average cell loss as compared with the control material is 48.8 %. The ventral cochlear nucleus had lost 41.8 % of its cells, and the dorsal cochlear nucleus up to 65 % of its cells.

Asphyxia neonatorum is a condition of great interest to otologists, as the surviving children may become hard of hearing. The clinical otological findings concerning the defects following asphyxiation or anoxia have been described by, among others, Fisch & Osborn (1954), Fisch (1955, 1956), Flottorp, Morley & Skatvedt (1957), Barr & Klockhoff (1959) and Zaner & Miller (1959).

The findings are nearly identical—a bilateral high frequency sensorineural hearing loss. This selective loss for high frequencies Fisch (1956) ascribes to a lesion in the dorsal cochlear nucleus, where high frequency conducting fibres project, as shown by Lewy & Kobrak (1936). Experimental procedures also show that anoxia reduces hearing ability. Windle (1943, 1944) in his comprehensive experimental investigations in guinea pigs and monkeys mentions hearing disorders in animals following asphyxiation. Among his neuropathological findings were marked neuronal changes in the geniculate bodies and the inferior colliculi. Lawrence & Wever (1952) produced severe anoxia in cats, and arrived at the conclusion that the organ of Corti was heavily affected. Their experiments were repeated by Elbe Hansen *et al.* (1958), who did not find any pathological changes in the organ of Corti in asphyxiated guinea pigs.

Experiments in man also show that lack of oxygen influences the auditory acuity. Spiesman & Gellhorn (1935) found an increase in the hearing threshold among persons inspiring air with a low oxygen content, and Seitz & Smith (1942) and Smith (1946, 1948) have shown that speech intelligibility decreases under conditions of anoxia. Klein (1958, 1959) found a decrement in the detectability of audio and vibratory signals both in a noisy and a quiet environment after exposure of male adults to lack of oxygen. The reports

mentioned leave the impression that neonatal asphyxia may affect the auditory centers, but as regards the degree and the distribution of the pathological changes we are still imperfectly informed

In an attempt to provide an answer to these questions the author has investigated the auditory centers of fatally asphyxiated children mostly premature Hitherto the brain, the brain stem and the cochlea of 38 children have been examined, with 6 non asphyxiated cases serving as controls In order to avoid post mortem changes, intraarterial injection of fixing fluid formalin or Heidenhain-Susa, was performed, in most cases about two hours post mortem It was injected through the ascending aorta, after ligating all other arteries than those leading to the brain Subsequently blocks of tissue comprising the auditory regions in the temporal lobes, the medial geniculate bodies, the inferior colliculi, and the cochlear nuclei were removed embedded in paraffin, cut serially at 15 μ, and stained with thionin

A cylinder of bony tissue, containing the cochlea was removed from the temporal bones, using a fast working drill In the first 24 cases the temporal bone specimens were treated in the orthodox way, formalin fixation and paraffin embedding which gave poor pictures, but later a method advised by Dr H Engstrom, of Gothenburg, was applied with considerable improvement in the results The microscopical examination of the auditory cortex the medial geniculate bodies and the inferior colliculi did not reveal definite pathological changes so far The cochlear nuclei, however, showed very remarkable changes All the classical degenerative changes described by Nissl were present, with transitions from a slight blurring of the contours of the cell and vacuolization of the cytoplasm to the barely visible remnants of a ghost cell (Fig 1)

Also other nuclei in the brain stem were affected Changes were found in the olive, the superior olivary complex, the Purkinje cells of the cerebellum and sometimes slight changes in the cells of the inferior colliculus Nowhere however, did the changes seem to be so striking as in the cochlear nuclei

The findings indicate a selective vulnerability to anoxia on the part of these nuclei, but it is extremely hard indeed to assess the changes in the nerve cells in the brains of these new born, often premature babies At the suggestion of Dr R Adams, of Boston, the author has tried to provide a numerical expression for the presumable affection of the cochlear nuclei It was postulated that where the nerve cells microscopically seemed extensively degenerated, there should also be a loss of cells

A method was then devised for counting the nerve cells of the cochlear nuclei The method described by Chow (1951) was adapted to fit a human material

The number of cells in a measured unit were counted in every 10th section Four to six units were counted in every section, which amounted to about a hundred units counted in each nucleus Then the average number of cells in a unit was calculated The volume of the nuclei was determined by drawing the outlines of the nuclei, using a Bausch and Lomb projection apparatus (Fig 2) The aberration in

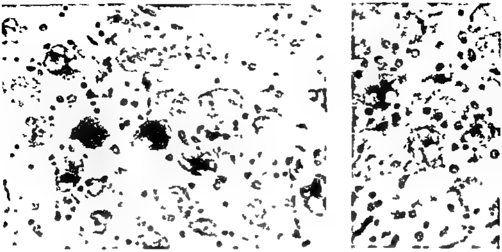

FIG 1 Degenerative changes in the cochlear nuclei Premature babies, dead following 18 and 13 hours of asfyxiation

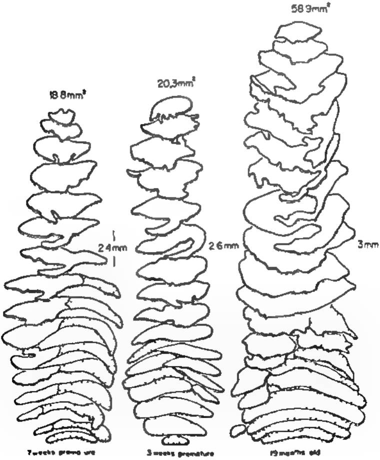

FIG 2 Drawings of serial sections of the cochlear nuclei (dorsal nucleus dotted)

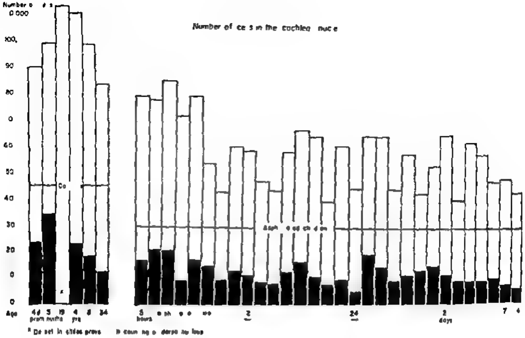

Fig 3

such a system was compensated using a plane apochromatic objective The magnification in this system was × 625 The areas of every 10th section were then measured using a planimeter The ventral and the dorsal cochlear nuclei were measured separately three times each, and the mean value calculated Knowing the areas of every 10th section the approximate volume of the whole nucleus could be calculated and having the mean number of cells in a given volume the total number could be computed

Such cell counts have been performed in the above mentioned material To avoid the possible error of counting twice one cell body (which may appear in more than one section) only those containing a nucleolus were counted More than one nucleolus in a cell was never seen

The problem of acquiring a suitable control material is great as nearly always a lack of oxygen is involved in the death mechanism of premature children Older children or adults dying suddenly have to be used for comparison Excluding sequelae of diseases the same number of cells should presumably be found in the cochlear nuclei of adults and newborn As appears from Fig 3 and Table 1 the number of cells decrease with an increasing asphyxiation time and it is also evident that the number of cells in the cochlear nuclei of the control material on an average lie far above the figures in the nuclei of the asphyxiated babies

The cell loss per cent is shown in Table 2 where also the relation between the number of cells in the ventral and the dorsal cochlear nuclei is presented It is furthermore evident that the greatest cell loss occurs during the first day and night

It would of course be of great interest to see whether these changes in the

TABLE 1 *Number of cells compared with time of asphyxiation*

Time: Days	Time: Hours	Both nuclei	Ventral cochlear nucleus	Dorsal cochlear nucleus
14	—	41 993	36 309	5 684
7	7	47,201	40 315	6 886
[illegible]	20	46 212	36 738	9 424
3	10	56 662	47 920	8 742
2	15	61 232	52 521	8 711
1	19	39 319	30 581	8 738
1	12	[illegible] 948	53 003	10 945
1	8	52 397	38 221	14 176
1	6	41,904	28 143	13 761
1	5	56 998	46 179	10 819
1	4	[illegible]	34 895	8 975
1	2 6	63 516	49 101	14 445
1	0–18	63 812	44 777	19 035
	20–30	43 684	38 690	4 994
	22	59 985	50 975	9 010
	20	39 892	31 839	7 003
	15 20	63 522	53 174	10 348
	15	66 006	49 789	16,217
	14 18	57 639	45 436	12,203
	13	43 193	35 229	7 894
	13	46 452	37 798	8 654
	12	58 167	4[illegible] 196	10 971
	11	59 763	47 388	12 375
	11	42 554	33 536	9 008
	10	53 384	38 959	14 425
	[illegible] 12	[illegible]	62 465	16 750
	9	71 515	62 428	9 087
	7 12	81 787	64 130	20 607
	5 7	78 189	57 485	20 704
	5	79 399	63 027	16 372

Number of cells in a control group

	Both nuclei	Ventral cochlear nucleus	Dorsal cochlear nucleus
Stillborn (14 days premature)	89 8[illegible]	69 53[illegible]	20 315
Suffocation ([illegible] months)	98 074	63 270	34 804
Invagination (19 months)	113 052	89 581	23 471
Car accident (4 years)	110 319[a]		
Acute nephritis (8 years)	98 870	80 [illegible]	18 [illegible]
Infarctus cordis (44 years)	83 71[illegible][a]	72 043	11 676

[a] Minimum figures part of the nuclei torn during preparation

cochlear nuclei are accompanied by changes in the inner ear of the same individual. Due to the difficulties in preparing a human temporal bone, however, only five of the 44 bilateral preparations of the inner ear proved to be of the standard required to distinguish between artefacts and possible

TABLE 2. *Cell loss compared with time of asphyxiation (%)*

The comparison involves the average number of cells in five controls

	Both nuclei	Ventral nucleus	Dorsal nucleus
Average max. loss	48.8	41.8	65.0
Loss during first 24 hours	38.0	33.7	44.2
Loss during remaining lifetime	10.8	8.1	20.8

changes due to asphyxiation. Some of these live with a normal structure of the inner ear have cell losses in the cochlear nuclei, a fact which at present can only be taken as a pointer. More material, including control material, has to be collected before any definite conclusions on this and related questions can be reported.

ZUSAMMENFASSUNG

Diese vorläufige Mitteilung zeigt, daß nach neonataler Asphyxie ein ausgesprochener Verlust von Nervenzellen in den cochlearen Kernen vorhanden ist. Der durchschnittliche Verlust beträgt mit dem Kontrollmaterial verglichen 48.8% der Zellen, und zwar im ventralen Kern 41.8%, weil in dem dorsalen Kern durchschnittlich 65% der Zellen verlorengegangen sind.

RÉSUMÉ

Dans une étude préliminaire des enfants morts d'asphyxie au temps de la naissance une perte considérable de cellules a été trouvée dans les noyaux cochléaires. La réduction moyenne est de 48.8 pour cent, celle du noyau cochléaire ventrale étant de 41.8 pour cent, tandis que celle du noyau dorsale est de 65 pour cent.

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The Anat mical Institute Oslo

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COLD CAUTERY TREATMENT OF LARYNGEAL PAPILLOMATOSIS[1]

TAUNO PALVA and OTTO H. MEURMAN
Turku, Finland

From the Department of Otolaryngology, University of Turku

The method of treating laryngeal papillomata with cold cautery is described and the results are reported in a far advanced case. Cold cautery treatment is recommended in all cases in which tracheotomy has been necessary and in all in which the application can be done under general intubation anaesthesia. The source of cold was liquid *oxygen* at a temperature of −180 C.

In young children in particular, laryngeal papillomatosis often presents features constituting a powerful challenge from the point of view of treatment. The small airway, which is further narrowed by masses of papillomata—sometimes to the point of obstruction—can be handled only gently, and even slight trauma may cause dangerous oedema of the subglottic spaces. The frequent recurrences may make the lives of some of these small patients miserable.

Many methods of treatment have been devised and advocated. Simple removal by forceps from time to time is all that is needed in the mild cases and the papillomata disappear after varying periods of time. Cauterization with chemical agents, e.g. using thrichloracetic acid, or electrocautery is often tried in addition to forceps removal in more severe cases. Finally, in some refractory subglottic cases, thyrotomy has been employed, the mucosa being peeled off together with the papillomata from the vocal cords and subglottic area.

Lemaries and Muler in 1960 published a report on the use of cold cautery for the treatment of laryngeal papillomatosis. Liquid nitrogen at a temperature of −180°C is used for the cooling of special applicators, which are quickly placed over the papillomata. The applicators are held in place for 10 to 15 seconds and the cauterized papillomata become white, oedematous, and eventually fall off. At the time of the publication of the above report we saw a very refractory case and decided to try the cold cautery treatment.

Notes on Cases

During the 10 year period 1951 to 1961 we have had 13 new cases of laryngeal papillomatosis under treatment at the Department. Eight of these were children under 15 years of age, three belonging to the group under 5 years of age. This group of three patients included the two that have caused us most concern and are described below, the second in greater detail.

[1] The financial support of the Sigrid Juselius Foundation is gratefully acknowledged.

The first case, a girl of 4 years, was under treatment from 1951 to 1955 and several removals of papillomata were made each year. Fortunately enough the papillomata were always limited to the glottic or supraglottic structures and the subglottic space remained free. Cure finally resulted after 5 years of treatment with three to six removals of papillomata each year.

The second patient was a 4 year old girl who had been hoarse since birth with at times great difficulties in breathing. At the age of 1½ years the first removals of papillomata were performed with forceps. Respiration continued to be difficult and there were sometimes severe dyspneic seizures. Papillomata were subsequently removed on many occasions; at the age of 4 years the patient was hospitalized in another clinic for 3 months. Several attempts were made to remove the papillomata by forceps and by chemical means, but the difficulties in breathing increased and tracheotomy was performed. The girl was discharged home wearing a cannula.

When first seen by us the patient was wearing her tracheotomy cannula and could not get along without it. She was quite hoarse, talking almost in a whisper; otherwise the general condition was good. We admitted the patient (1960) and gave her fluothane anesthesia via the tracheal cannula and examined her larynx by direct laryngoscopy. Large masses of proliferating papillomatous tissue were seen to fill the laryngeal aperture, hanging over the hypopharynx and growing over both ventricular bands and the whole under surface of the epiglottis. It was obvious that many papillomata were also growing below the vocal cords; they did not, however, reach the tracheotomy opening. In contemplating the appropriate therapy it seemed that resort to conventional methods would be of no avail, as indicated by the history cited above. Performing thyrotomy on a girl of this age seemed out of the question. Encouraged by the results of Lemariey and Muler, we therefore decided to try the cold cautery method.

Method of Treatment

The required cooling of suitable instruments may be obtained by using either liquid nitrogen or liquid oxygen. Liquid nitrogen would be safest as it is absolutely non-inflammable; however, with the local gas plant we would have been able to obtain liquid nitrogen only occasionally, whereas liquid oxygen was available daily. We began using liquid oxygen which was obtained in special Dewar containers holding 5 liters. The only precaution taken was to forbid any open fire or spark emitting system in the operating room.

It is important to note that the lid of the Dewar container must not be locked but only placed loosely on the top. Otherwise the evaporating oxygen would burst the container when the pressure of the trapped gas grows sufficiently high. An amount of 5 liters lasts for three days. By this time all liquid has evaporated.

The special applicators (Fig. 1) were made of rather thick electrical insulated copper wire. The insulating cover was removed from one end for a

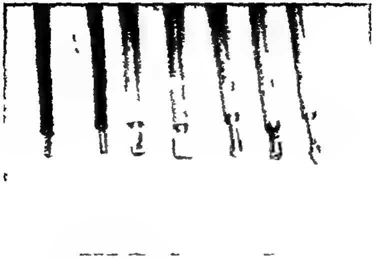

FIG. 1. Copper sticks with heads of various shapes and sizes.

length of 3 cm, and the heads were prepared in several sizes and shapes to meet the various situations in the larynx.

The applicators are placed in the Dewar container for 5 minutes before commencing the cautery so that the bare heads become thoroughly frozen. At first the liquid oxygen boils extensively around the copper stick endings, but after cooling takes place, only natural evaporation remains. The assistant always keeps several sticks in readiness to ensure the uninterrupted work of the operator.

In direct laryngoscopy the operator applies the bare, cold end of the stick to the papillomatous surface, and the stick immediately becomes adherent to the papilloma. If it is removed within a few seconds, papillomatous tissue frozen to the end of the stick follows with it and a slightly bleeding surface remains. If it is kept in place for 10 to 20 seconds it loosens of itself and when removed, leaves a white coagulated surface. Applications are made until all papillomatous tissue has been cauterized.

All applications should be made on to a dry papillomatous surface and not to bleeding areas, because the effect of the cautery is so superficial that the required cauterizing effect will be lost. Using suction and then waiting for a few seconds, the operator can always get dry surfaces to work with.

The Course of Treatment

During the first phase of the treatment the little girl was kept hospitalized for 1½ months, and cold cautery applications were made two or three times weekly under fluothane anesthesia. There were altogether 15 cautery sessions. Looked at in retrospect, we were much too cautious at the beginning, not being familiar with the effect of the cautery. During the latter part of this period we began to use forceps removal of superficial papillomata combined with cauterization of the raw surfaces with the copper sticks. This resulted

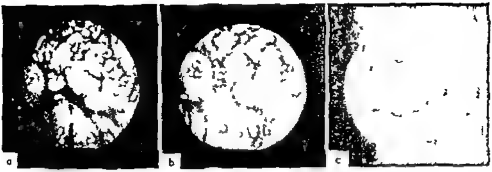

FIG. 2. First laryngeal appearances. Initial view (left) and first (middle) and second (right) post-cautery session views.

in a much more rapid disappearance of the papillomata; at the end of the period all superficial laryngeal structures were free of papillomata and the subglottic papillomata had been removed with forceps.

The three pictures (Fig. 2) from our 8 mm film clearly demonstrate the large masses of papilloma at the early period of treatment. When the normal supraglottic stage was reached we thought our troubles were over and removed the tracheotomy tube. Respiration was unimpeded and the voice reasonably good.

The patient was at home for 4 weeks and was then readmitted for a follow-up laryngoscopy. She had become hoarse again and it was evident that some regrowth of the papillomata had occurred. Direct laryngoscopy (Fig. 3 left) revealed papillomatous tissue on the right ventricular band and over the right arytenoid, as well as on the under surface of the epiglottis. Subglottic papillomata were also present and were clearly the cause of the

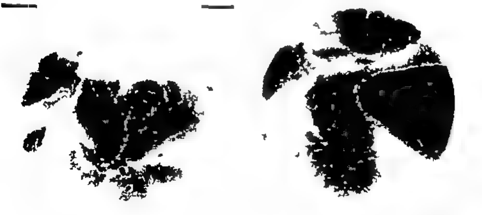

FIG. 3. Laryngeal appearance after the recurrence with papillomata over the right ventricular band, right arytenoid and under surface of epiglottis (left). A cauterizing stick over the right ventricular band (right).

FIG 4 A broad cautery stick in the subglottic area (left) Final view with the glottis closed (right)

recurrence of hoarseness As it was obvious that no successful treatment was possible without tracheotomy this was performed and a cannula inserted

After this we had the patient at the hospital once a month for a week at a time and made two or three cauterizations at a time destroying all visible papillomata The main difficulty naturally was to eradicate the subglottic papillomata as the sticks could not be introduced into this area without their being caught in the vocal cords

This difficulty was overcome by spreading the vocal cords at the posterior commissure either with a broad suction tip or with an uncooled large headed copper stick which held the glottic chink open and allowed the introduction of the frozen copper sticks for subglottic cauterization of the papillomata

After reinsertion of the tracheal cannula the patient was admitted seven times to the Department for a weekly treatment The last sessions of treatment were short as only minor papillomatous regrowth appeared Finally when the child had been two months without recurrence of growth the tracheal cannula was removed and the stoma was allowed to close The child has been seen regularly afterwards her larynx shows slight thickening of the right ventricular band (Fig 4 right) but is otherwise normal and her voice is good

Pathological Anatomy

Several pieces of tissue were studied histologically and all of them presented characteristics of benign juvenile papilloma of the larynx The surface consisted of thick keratinizing squamous epithelium of regular appearance Some morphologically regular mitotic divisions were seen in the epithelium The subepithelial tissue was generally thin oedematous containing many areas rich in capillaries (Figs 5 and 6)

Fig 5 Low power view of the papillomata there is a thick keratinizing epithelium with thin oedematous subepithelial tissue

General Remarks on Cold Cautery Treatment

If the application of cold cautery could be done without danger of laryngeal spasm or subglottic oedema we would recommend it for use in most

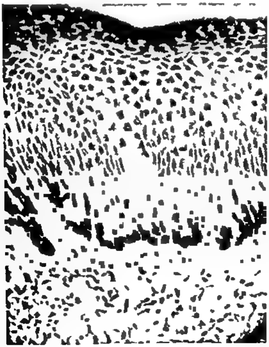

Fig 6 High power magnification of the epithelium the squamous keratinizing epithelium is of normal appearance with regular mitotic divisions

of the cases However, owing to the localization of the lesions, this special cautery is associated with certain limitations and it should be used in properly selected cases

If a case does not respond to ordinary methods and needs a tracheotomy for relief of respiratory distress it is ideal for cold cautery treatment To speed up the eradication of the papillomata, gentle forceps removal should also be employed cautery is always used afterwards to coagulate the raw surfaces, and this seems to prevent regrowth very effectively Using this *combined method, a few sessions should suffice for getting rid of the papil*lomata, although, as shown by our case, the cannula should only be removed after sufficiently long time of observation

There is another type of cases in which we believe the cautery can be used effectively children or adults, in whom the papillomata are located above the glottic aperture and in whom intubation can be used without fear of subsequent subglottic oedema Although Lemariey and Muler treated some of their cases under local anesthesia, we are not in favour of it because the patient's breathing during the insertion of the stick makes the laryngeal area foggy and strictly correct placement of the stick is difficult

If papillomata occur in the subglottic area, any method of treatment must be preceded by tracheotomy In these cases the present method seems to offer the best chances of a permanent cure without harming the normal laryngeal structures

Furthermore, cold cautery treatment is greatly preferable to hot cautery the former causes superficial necrosis of the papillomata without damaging the underlying tissues, whereas the latter can cause deep burns with subsequent scarring and adhesions in the anterior commissure with the result that both the airway and the voice may suffer permanently

ZUSAMMENFASSUNG

Es wird eine Behandlungsmethode von Larynxpapillom mit kalter Kaustik beschrieben und uber die Resultate bei einem weit vorgeschrittenen Fall berichtet Kalte Kaustik wird bei allen Fallen empfohlen, wo eine Tracheotomie durchgeführt werden musste und wo der Eingriff in Allgemeinnarkose vorgenommen werden kann Die Kaltequelle war flussiger Sauerstoff von −180°C Temperatur

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MIDDLE EAR EFFUSIONS PRODUCED EXPERIMENTALLY IN DOGS

III Further studies concerning the pathogenesis of the effusions

BEN H SENTURIA, M D CHARLES D CARR M T and
BENJAMIN ROSENBLUT, M D
St Louis Mo, U S A

From the Department of Otolaryngology Washington University School of Medicine, St Louis, Missouri

Middle ear effusions were produced in dogs by cauterizing the nasopharyngeal orifices of the eustachian tube Cauterization of the actual tubal orifice was essential for producing the effusion Injury to the contiguous wall of the nasopharynx, no matter how close to the tubal opening did not result in an effusion *Serous, seropurulent purulent* and *mucopurulent* effusions were obtained in approximately one half of the cauterized ears These revealed characteristics similar to those seen in human effusions Positive bacterial cultures were obtained from approximately three fourths of the effusions A high percentage of streptococci were cultured concomitantly from the middle ear effusions and the corresponding nasopharynges Differences in the cytologic and physical characteristics of the effusions are attributed to individual immunologic responses

Despite much clinical and some experimental research the problem of middle ear effusions still presents many unsolved questions both in its physio pathological aspects and in its clinico therapeutic implications

Several studies have been reported on experimental middle ear effusions in which attempts were made to reproduce the conditions of otitis media in its different modalities In general the trends of the experimental studies have followed three different patterns One group has attempted to close the nasopharyngeal opening of the eustachian tube by various surgical procedures in an effort to produce middle ear effusions Very typical of this group are the experiments of G Holmgren (1934) and L Holmgren (1940) but the manner in which the effusions were produced remains open to discussion Claus (1930) after trying to produce hydrops *ex vacuo* by many different methods denied the feasibility of reproducing this condition in the laboratory

Effusions of the middle ear have also been produced by subjecting animals to changes in atmospheric pressures (Aschan 1948 Campbell 1947) As a rule these were serous effusions without inflammatory characteristics although markedly bloody fluids were also found

These studies were performed under grant [illegible] National Institute of Neurological Diseases and Blindness National Institutes of Health Public Health Service

A third method of producing middle ear effusions was by trans tympanic instillation of pathogenic bacteria. Early studies of this nature were reported by Haymann (1912) and more recently Friedmann (1955) described extensive histo pathological middle ear changes resulting from the use of this technique.

Most of the earlier approaches required a surgical procedure on the soft palate in order to obtain necessary visualization of the nasopharyngeal orifice of the eustachian tube. Reduced atmospheric pressure produced only a transitory serous type of effusion while trans tympanic instillations introduced a massive overwhelming infection seldom seen in practice. None of these methods provided a satisfactory laboratory procedure wherein the contributing factors were subject to control.

The necessity for further information is evident. Of late much discussion has revolved around the unifying theory (Senturia *et al* 1958) concerning the pathogenesis of otitis media with effusion in which all the categories of middle ear effusions are considered different stages of the same phenomenon.

Recently Senturia and associates (1958) utilized a method whereby a closer approach to the natural condition was intended. In these experiments inflammation and local reduction of the defenses of the eustachian tube were produced without causing extensive damage to the rest of the nasopharynx.

The current studies continue this work with a larger number of dogs and more rigid control of the experimental conditions. This communication will deal essentially with the method for producing the effusion and the cytological and bacteriological findings. The histo pathological investigation still in progress will be reported later.

METHODS

The previous report (Sade *et al* 1959) has shown that the dog is very suitable for this type of research. In most instances the relatively wide oral cavity and nasopharynx provides enough room for the visualization of the eustachian tube orifices without requiring surgical procedures on the soft palate.

Thirty one mongrel dogs (62 ears) were used in this study. The animals were vaccinated for rabies and canine distemper and maintained in isolation for two to three weeks prior to their use in this experiment. On the day of cauterization (0 day) the animals were weighed, anesthetized with intravenous nembutal sodium (60 mg/kg) and to avoid the pharyngeal reflex a 10% solution of cocaine was sprayed into the nasopharynx.

Both external ear canals were cultured. Any cerumen present was removed and the tympanic membranes were examined. The nasopharynx was then cultured and blood for biochemical studies was drawn. Routine laboratory techniques were employed in the bacteriological studies.

The nasopharyngeal orifices of the eustachian tubes were visualized by elevating the soft palate with a specially designed retractor. A galvano

TABLE 1 *Number of ears cauterized (tubal orifices)*

Cautery	Ears	Dog
Bilateral	36	18
Unilateral	[illegible]	13
Controls	[illegible]	
Total	62	31

cautery tip was then introduced into the opening and current applied for 10 seconds In each of 13 dogs (13 ears) one tube was cauterized on 0 day and the contralateral orifice (13 ears) was kept as an untreated control In 18 dogs (36 ears) both tubal orifices were cauterized Bilateral cauterizations were performed on seven of these animals on 0 day The remaining 11 had only one orifice cauterized on 0 day, the contralateral openings were cauterized seven days later Thus there were 49 cauterized ears and 13 controls (Table 1)

Because of anatomical limitations, good visualization of the tubes was not obtained in some of the dogs and uncertainty existed as to whether nor not the cauterization procedure had been successful It was possible, however to re examine and describe the tubal orifices in those animals in which there was a one week interval between cauterizations

After periods ranging from three days to seven weeks the dogs were again anesthetized, cultures of the external ear canals and nasopharynges were repeated and the tympanic membranes examined Any fluid present in the middle ear cavities was aspirated into sterile containers smears for cytologic examination were prepared and one loopful of the fluid was inoculated into culture media The remaining effusion was stored in deep freeze for later biochemical studies

The animals were sacrificed with intravenous pentothal sodium and 0 1 ml of 10 % formalin was injected trans tympanically into the middle ear and bulla Each temporal bone with attached eustachian tube and contiguous nasopharynx was then removed and placed in formalin

To classify the fluids obtained a modification of a previously proposed nomenclature based on macroscopic and microscopic characteristics of middle ear effusions was used (Senturia *et al* 1958) thus dividing the dog middle ear effusions into five categories *serous* *seropurulent*[1] *purulent* *mucopurulent* and *mucoid*

RESULTS

The number of effusions and the post cauterization intervals at which they were obtained is shown in Table 2 In 26 specimens or slightly more than

[1] Seropurulent has been designated for those fluids which are of low viscosity pale yellow and slightly turbid in appearance and containing a variety of cells with macrophages predominating

TABLE 2 *Number and categories of effusions obtained at various intervals of aspirations after cautery*

Post cautery interval (days)	Number of ears aspirated	Total number of effusions	Type of effusion[a]			
			S	SP	P	MP
3	1	1	1			
6	1	1				1
7	9	8	1	1	3	3
14	10	6		1	4	1
21	10	9		[illegible]	5	1
28	2	0				
35	3	1	1			
42	7	0				
49	6	0				
Totals	49	26	3	5	12	[illegible]

[a] Lettered symbols of types of effusions indicate S = serous SP = seropurulent P = purulent, MP = mucopurulent

one half of the cauterized ears (53 %) it was possible to aspirate fluid from the middle ears Six were bilateral while the remaining fourteen were unilateral effusions [1]

The greatest incidence of effusions was found from 3 to 21 days post cautery, occurring in 25 out of 31 ears (80 6 %) In the period 28 to 49 days post cautery, only one of the 18 ears was positive for fluid (5 5 %)

Table 2 also shows the various categories of the fluids based on their physical and cytologic characteristics and the post cautery interval at which they were aspirated There appeared to be no consistent relationship between the category of effusion and the length of time it had been present in the tympanum, although the mucopurulent effusions appeared to occur earlier than the purulent and seropurulent The three *serous* fluids, showing the typical straw color, low viscosity and acellular characteristics were obtained after periods of 3, 7 and 35 days Five *seropurulent* with an increase in the number of cellular components, particularly the macrophages, and 12 *purulent* showing myriads of intact polymorphonuclear leucocytes occurred between seven and 21 days Six *mucopurulent* specimens containing numerous cell remnants and mucus like strands were aspirated from [illegible] to 21 days post cautery

Evidence of the cauterization was manifested by various types of nasopharyngeal lesions In the animals allowed to survive seven days or less the most common form was a large necrotic ulceration of the tubal opening

[1] A negative aspiration of the successfully cauterized ears does not necessarily indicate that an effusion did not develop It is possible that the viscosity of the effusion was such that it could not be withdrawn or that organization of the exudate had progressed so rapidly that the effusion could no longer be aspirated These points will be clarified when the histo pathologic studies are reported

TABLE 3 *Distribution of microorganisms cultured from middle ear effusions*

Microorganisms	Effusions Number	Effusions Per cent
Streptococcus beta hemolytic	6	23 1
Streptococcus non hemolytic	5	19 2
Staphylococcus epidermidis	8	30 8
Coli aerogenes group	3	11 5
Proteus vulgaris	3	11 5

and the peritubal mucosa In those from 14 to 21 days polypoid granulation tissue was either protruding from the orifice or covering it in some instances fibrosis was occurring Seven of the animals surviving longer than 21 days demonstrated grossly what appeared to be partial or complete occlusion of the eustachian orifice There was no apparent relationship between the type of lesion present and the period the animals were allowed to survive after cauterization

Nor was there any apparent relationship between the type of tubal lesion and the category of effusions obtained A wide distribution of effusions was found during the various stages of healing A serous effusion was present as early as the third day and as late as 35 days in one of the long term ears in which the gross appearance of the orifice was normal

Nineteen of the 26 middle ear effusions obtained were positive for bacterial growth (73 %) and nine of these showed bacteria in direct smears of the fluids The microorganisms most frequently cultured were the different species of streptococci[1] *beta hemolytic Streptococcus* was present in 23 1 % and *non hemolytic Streptococci* in 19 2 % of the effusions *Staphylococcus epidermidis* (coagulase negative staphylococci) were found in 30 8 % while gram negative bacilli (*Coli* aerogenes group and *Proteus vulgaris*) accounted for 11 5 % of the effusions cultured No growth occurred in 26 9 % of the fluids (Table 3)

There was no apparent relationship between the age of the effusion and the incidence of positive cultures Bacterial growth was present in seven out of ten effusions occurring in the first seven days in 11 out of 15 effusions collected between 14 and 21 days and in the one effusion obtained after 21 days The same genera of bacteria were found in the different categories regardless of the post cautery interval

Table 4 shows the bacteria cultured from the nasopharynges A variety of microorganisms was present in the cultures of a majority of the animals In both the pre and post cautery cultures the *beta hemolytic Streptococcus* was frequently encountered occurring in 54 8 % of the cultures on 0 day

[1] Differentiation of the streptococci was based on surface growth and morphologic characteristics only

TABLE 4 *Incidence and percentage of microorganisms cultured from the dog nasopharynx*

Microorganisms	Pre cautery Number	Pre cautery Per cent	Post cautery Number	Post cautery Per cent
Streptococcus alpha hemolytic	2	6 4	3	10 7
Streptococcus beta hemolytic	17	54 8	19	67 9
Streptococcus non hemolytic	14	45 1	12	42 9
Staphylococcus epidermidis	21	67 7	18	64 3
Coli aerogenes group	15	48 4	11	39 3
Proteus vulgaris	1	3 2	0	0
Corynebacteria	1	3 2	0	0
Hemophilus sp	0	0	7	25 0

TABLE 5 *Incidence and percentage of microorganisms cultured from the dog external ear canal*

Microorganisms	Pre cautery Number	Pre cautery Per cent	Post cautery Number	Post cautery Per cent
Streptococcus alpha hemolytic	0	0	1	1 7
Streptococcus beta hemolytic	0	0	3	5 1
Streptococcus non hemolytic	3	4 8	2	3 4
Staphylococcus epidermidis	45	72 6	41	70 7
Coli aerogenes group	3	4 8	5	8 8
Proteus vulgaris	1	1 6	1	1 7
Corynebacteria	7	11 3	3	5 1

with an increase to 67 9 % on the day of sacrifice The incidence of *Staphylococcus epidermidis*, *Coli aerogenes* and *non hemolytic Streptococci* groups of organisms were not markedly changed in the pre and post cautery cultures Of interest is the appearance of Hemophilus species in seven post cautery cultures

The results of the pre and post cautery cultures of the ear canals are shown in Table 5 The data for the right and left ears are presented together since there was no appreciable difference between the organisms cultured from the two ears In the main a heterogeneous miscellanea of orgaisms was found with *Staphylococcus epidermidis* predominating It is interesting that in the post cautery cultures *beta hemolytic Streptococci* were recovered from three ear canals

DISCUSSION

It is evident from our data that it is possible to produce middle ear effusions in the dog by galvano cauterization of the nasopharyngeal orifice of the eustachian tube This fact was reported earlier from this laboratory (Sade *et al* 1959)

During our studies cauterization was actually attempted in 54 tubes of these only 49 were utilized in this study At the time of sacrifice the other five showed the cautery point to be at distances of 1 mm to 1 cm from the tubal orifice and so were rejected as unsuccessful No effusion was aspirated from the five ears in which the tubal orifice was missed but was obtained in 26 out of 49 ears in which there were successful cauteries It therefore appears that the site of trauma is of utmost importance A lesion produced on the torus or on the nasopharyngeal wall no matter how close it may be to the eustachian tube orifice does not result in the production of a middle ear effusion so far as is shown by aspiration Only when the tubal orifice is cauterized (and then not always) does fluid collect in the middle ear and bulla

There was no typical lesion produced by cautery of the tubal orifice Although the method and time of application of the electric current was constant for all animals the size and appearance of the resulting lesions varied widely A number of animals showed large simple or granulated ulcers at the site of the tubal orifice others exhibited polyploid granulation tissue protruding from the orifice In some of the animals particularly the long term dogs gross examination showed the opening to be partly or completely scarred or deformed but with the configuration of the tube maintained in others the tubal orifice appeared normal except for a thickening and discoloration of the epithelium

Microscopic examination of the effusions revealed compositions similar to those reported previously (Sade *et al* 1959) except for the fluids classified as seropurulent The cytologic findings of the effusions did not differ greatly from those reported for the human (Senturia *et al* 1958) and demonstrated the striking similarity of spontaneous human to experimentally produced effusions

There was no apparent relationship between the type of tubal lesion and the category of effusions produced One would have assumed that for those ears in which the tubal opening was stenosed a serous type of effusion should have formed due to negative pressure occurring in the tympanum It was also expected that a purulent otitis media would have occurred consistently in those cases in which ulceration of the tubal orifice was noted Instead the various categories of fluids were widely distributed

Similarly there was no evidence that the type of effusion produced was related to the length of time the fluid remained in the middle ear in fact the purulent category was most frequently aspirated between seven and twenty one days Examination of the fluid revealed that in most instances cellular degeneration was not occurring thus indicating that a low grade or subacute type of inflammation was present with a constant migration of leucocytes into the tympanum

The variations in the cytologic and physical characteristics of the fluids cannot be explained by the bacteriological findings but might be attributed to individual characteristics of the animal The existence of a different local

or general immunologic capacity in each dog at the time of the experiment could explain the diversity of reactions. A speculative concept concerning human middle ear effusions was recently proposed (Senturia *et al.* 1960) which could also apply in this study. According to this hypothesis, the largest percentage of middle ear effusions is inflammatory in origin, and the various types of effusions are expressions of the same pathologic process arrested at different stages of development according to the subjects' immunological response. We believe that our present data supports the foregoing hypothesis.

In the cultures of the middle ear effusions, the most frequent organisms were *beta* and *non-hemolytic Streptococci*. A number of cultures showed only *Staphylococcus epidermidis*, but since the latter are usually considered skin inhabitants, it is assumed that they were introduced from the external canal into the middle ear at the time of aspiration of the fluid.

A small number of the effusions showed bacteria present in direct smear and all but one of the corresponding cultures were positive for bacterial growth. Seven effusions from which only *Staphylococcus epidermidis* was cultured were negative for organisms when smears of the fluid were examined microscopically. McBride (1953), studying otorrhea in dogs, reported that the most common bacteria cultured from "easily cured" ears were *Staphylococcus aureus* and *albus* and occasionally Streptococcus. *Pseudomonas aeruginosa and Escherichia coli occurred in a majority of cases of persistent* external and middle ear infections. Both Friedmann (1957) and Senturia *et al.* (1958) reported a predominance of staphylococcus in cultures of human middle ear effusions.

In cultures obtained from the nasopharynx following cauterization of the tubal opening, there was a slight increase in the incidence of *beta hemolytic Streptococcus*. The production of an inflammation in the nasopharynx apparently permits the hemolytic streptococci to find their way up the lumen of the tube into the middle ear and participate in the formation of the effusion. There is a striking similarity here with the events which occur following irritation of the nasal orifice of the naso-frontal duct. Irritation of this orifice regularly results in the establishment of infection within the frontal sinus (Walsh 1943).

No explanation for the appearance of Hemophilus species in the post-cautery nasopharyngeal cultures can be offered. It is very similar to the type-specific *Hemophilus influenzae* which produces acute respiratory infections in man (Dubos 1958). The presence of *Hemophilus influenzae* in cultures of the nasopharynx and not in the middle ear effusions is of interest since Suraja (1954) reported that *Hemophilus influenzae* was not inhibited *in vitro* by middle ear fluid obtained from humans with otitis media with effusions. In general, the bacteriological findings of the dog nasopharynx are a confirmation of those previously reported (Sade *et al.* 1959).

A large variety of non-pathogenic bacteria was found in the external ear canals, with a predominance of *Staphylococcus epidermidis* present in almost all of the ears. As one might anticipate, since there was no manipulation of

the external ears and no otorrhea produced there were no appreciable differences between the pre and post cautery cultures A point of interest is the incidence of gram negative bacilli (Coli aerogenes group and *Proteus vulgaris*) in the normal external ear canal of the dog This is somewhat higher than that reported for the normal external ear canal of the cat (Senturia & Carr, 1958) and the human (Senturia 1945 Singer *et al* 1952 Bablik 1955)

We are not prepared at this time to discuss the pathogenic sequence that will result in a middle ear effusion Inflammation of the nasopharyngeal mucosa a dysfunction in the sphincter mechanism and an ascending bacterial infection through the impaired defenses are possible causes for this chain of events It would appear likely that local interference with the normal physiologic function of the tube viz the lymphatic drainage and ciliary flow toward the nasopharynx with a retrograde extension of infection up the eustachian tube towards the middle ear is the primary factor in the patho *genesis of the effusion*

ZUSAMMENFASSUNG

Mittelohrexsudate an Hunden wurden durch Kauterisation der nasopharyngealen Öffnungen der Eustachischen Rohren hervorgerufen Um ein Exsudat zu erhalten war es wesentlich dass die Rohren direkt an ihren Ausgang kauterisiert wurden Traumatisierung nur der angrenzenden Gebiete des Nasopharynx wenn auch sehr nahe der Öffnung fuhrte zu keinen Exsudaten Serose seropurulente purulente und mucopurulente Ergusse wurden in annahernd der halfte der kauterisierten Falle erzielt Diese Ergusse wiesen die gleichen charakteristischen Merkmale auf, wie die am Menschen beobachteten Bei ungefahr 75 % dieser Exsudate ergaben die Zuchten positive Bakterienkulturen Aus den Mittelohrergussen sowie dem ent sprechenden Nasopharynx konnte ein gleich hoher Prozentsatz von Streptokokken gezuchtet werden Unterschiede in den zytologischen und physiologischen Eigenschaf ten der Ergusse wurden einer unterschiedlichen individuellen immunologischen Reaktionsweise zugeschrieben

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Ben H Senturia, M D Dept of Otolaryngology, Washington University School of Medicine, St Louis 10, Mo U S A

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OSSICULAR CHAIN DEFECTS

Diagnosis and Treatment

H. C. Andersen, O. Jepsen and E. Ratjen

Aarhus, Denmark

From the Departments of Otolaryngology and Neuroradiology, University of Aarhus

Defects of the ossicular chain as a cause of conductive deafness are apparently more frequent than is generally assumed. These causes are principally traumatic lesions, sequelae of infections and, less frequently, developmental anomalies. Radiography and tests for the stapedius reflex play an important part in the diagnosis.

By ossiculoplastic surgical measures it is possible to obtain considerable hearing gains of a permanent character. Experiments on the sound transmission in the middle ear have shown that in these reconstructions it is possible to obtain sound conduction which is very near to normal.

The transtympanic approach used in modern surgery for otosclerosis has extended our knowledge of the pathology of the middle ear. We now know that in the presence of a normal tympanic membrane and normal tubal function, conductive deafness is not always referable to otosclerosis, but may be due to an interesting conductive lesion which has received little attention in the past, viz. defects in the ossicular chain.

During recent years this affection has been described by a large number of authors (Bauer 1958, Elsberg & Floberg 1960, Gisselsson 1958, Goodhill 1960, Hajek 1961, Hamberger & Lidén 1958, Hough 1959, Riskær 1960, Schuknecht & Trupiano 1957, Shambaugh 1958, Sooy 1960). Not only the high frequency of the lesion and the great possibilities offered by surgical therapy, but also the diagnostic problems justify continued mention of this disorder of the middle ear.

The symptomatology of these ossicular defects differs only on a few points from that of otosclerosis, viz. in that the hearing loss (1) is usually unilateral, (2) is stationary, (3) is rarely accompanied by tinnitus, and (4) is in most cases referable to well defined events, such as traumata, infections, etc., or is congenital.

The lesion of the ossicular chain is almost invariably localized to the incus, in particular, to the long process and the incudo-stapedial joint. Dislocation or necrosis of the incus may here be encountered. The cause of this localization is that the incus, both from an embryological and from nutritional and static points of view, is the weakest link of the ossicular chain.

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Although as already mentioned, the tympanic membrane is usually normal ear microscopy may sometimes reveal abnormalities of the ossicular chain especially in the presence of severe dislocation of the incus

When the hearing loss is due to congenital malformation of the ossicles other developmental anomalies are often present Thus in our series we have encountered three cases of co existing slight deformities of the external ear in spite of a normal auditory canal and eardrum and in one case defective development of the right hand was observed

In our experience the test for the stapedius reflex is one of the most reliable methods in the audiological diagnosis of this type of usually unilateral conductive hearing loss This reflex can be elicited by acoustic stimulation or as a cutaneous reflex by blowing air on to the outer surface of the auricle (Djupesland 1961) The stapedius reflex is demonstrated by the fact that a contraction of the stapedius muscle produces a change in the impedance of the tympanic membrane but a prerequisite for this occurrence is that the ossicular chain is intact and mobile In the presence of defects or fixation the change in impedance fails to occur for which reason the stapedius reflex cannot be demonstrated The reflex is recorded by a so called acoustic measuring bridge (Metz, 1946) or an electro acoustic device (Terkildsen & Scott Nielsen 1960)

Of other methods may be mentioned the so called Schall Sonde method (Zollner 1957) but this has not been used in our series

Clinical Series

Our series consists of 34 cases which were diagnosed and treated within the last two years

On the basis of the aetiology the series may be subdivided into three groups

1 *Congenital malformations* (four patients) —In three of these the malleus was deformed and in osseous connexion with the posterior wall of the ear canal whereas partial aplasia of the incus was observed in the fourth patient Three of the patients showed slight malformation of the auricle and the fourth malformation of one hand

2 *Traumatic lesions* (18 patients) —Twelve of these patients had sustained head injuries usually associated with haemorrhage from the homolateral ear and in two cases escape of cerebrospinal fluid In two patients the cause was a perforating lesion of the tympanic membrane with dislocation of the incus (*paracentesis lesion caused by a hairpin*) and in four cases previous antrotomy had resulted in dislocation of the incus

Traumatic defects are the most important lesions of the ossicular chain not only in this series but also as far as treatment is concerned The relatively large number of cases in this group calls for more intensive otological control and check up examinations of patients with head injuries and for a greater clinical interest in hearing loss persisting after otherwise successful operations in the mastoid region

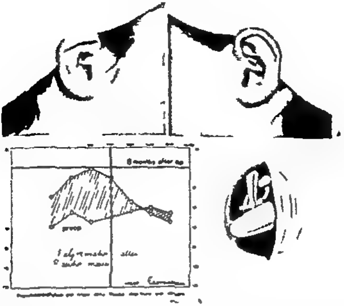


Fig. 1. Slight malformation of the auricle in a patient with congenital malformation of the malleus. Audiogram shows hearing gain after cutting the osseous bridge between the malleus and the posterior meatal wall.

3. *Inflammatory necrosis of the long process of the incus* (12 patients) — Otitis media and its sequelae are a rather commonly observed cause of incudo-stapedial joint separation, as the long process of the incus is more vulnerable to damage from inflammation than any other portion of the ossicular chain. One case of complete necrosis of the incus after radiation therapy for cancer of the rhinopharynx also belongs to this group.

Radiology

In the radiology of the lesions considered here the principal object is to clarify the topography of the middle ear.

On the basis of the radiographs it must be possible to decide if the form, size and position of the ossicles are normal, and also if there are any fracture lines, blurring or malformations of the tympanic cavity.

Such radiographic studies make heavy demands on both the examiner and the technique employed because the dimensions of the ossicles are very close to the limit of recognizable features in tomography.

Our patients were subjected to:

1. *Conventional radiographic examination* in eight different projections. Two proved to be of particular value, viz. the transorbital and Chausse's third projection, but in our experience this form of examination is of value only when severe malformations or fractures with considerable diastasis are present.

Of the 31 patients examined, only 10 revealed pathological features.

FIG 2 Traumatic dislocation of the ossicles on the right side in a 47 year old male patient *A* Tomography in the antero posterior projection on the right pathological side Medial dislocation of the malleus abnormally wide lateral tympanic recess Normal left side for comparison *B* Tomography in the lateral view on the right pathological side The malleus is placed in an abnormal cranial position and the space behind it is empty the incus could not be demonstrated Normal side for comparison *At operation* The incus was not found

2 Tomography The examination is performed with the Polytome in two projections (antero posterior and lateral view) using a 0 3 mm focal spot and hypocycloid movement of the tube In the antero posterior projection the distance between the layers is 2 mm while it is only 1 mm in the lateral view Of the 21 patients examined 16 revealed pathological features

The agreement between the results of the radiographic studies and the operative findings is analysed below for each of the clinical groups (malformations of the tympanic cavity traumatic lesions of the ossicular chain inflammatory necrosis of the long process of the incus)

Fig. 3. Traumatic dislocation of the left incus in a boy aged 5. A. Tomographs in the antero-posterior projection. The long process of the left incus is seen protruding just below the spur. B. Left lateral view. The incus placed in a plane lateral to that of the malleus is lying alone. Normal right lateral view for comparison. At *operation*. The incus was dislocated caudally and ventrally with the long process pointing in the lateral direction.

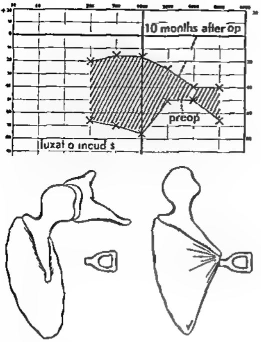
Four patients with small malformations of the tympanic cavity. While only one patient revealed evidence of a pathological process at the conventional radiographic examination, tomography resulted in pathological findings in all four cases.

Agreement between the radiographic examination and the operative findings was demonstrated in two patients. In the remaining two only partial agreement was observed.

Eighteen patients with traumatic lesions of the ossicular chain. Conventional radiography revealed a pathological process in 6 cases, while the pathological change was disclosed by tomography in 10 cases.

In all cases in which the dislocation was associated with a displacement of the body of the incus and/or the malleus, agreement between the radiographic examination and the operative findings was demonstrated.

In 11 patients operation revealed a dislocation and a defect of the incudo-stapedial



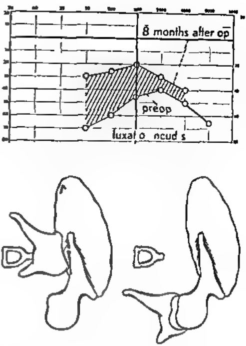


Fig 4 Fig 5

Fig 4 Myringostapediopexi in a patient with traumatic incus dislocation in the left ear
Fig 5 Interposition of the incus between the tympanic membrane and the head of stapes in a patient with traumatic incus dislocation in the right ear

joint or a fracture of the stapes The radiographic findings in these patients were either normal or only questionably pathological

Inflammatory necrosis of the long process of the incus (12 patients) —Only in three patients did conventional radiography and tomography reveal a pathological process

In all but two cases there was disagreement between the radiographic findings and those revealed at operation

Complete agreement between the radiographic and operative findings was thus found in a total of 11 cases In other words complete agreement was obtained in two thirds of the patients in whom tomography had revealed pathological features

In summarizing the results of our studies it may be said

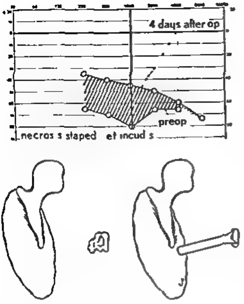
1 That in the presence of malformations or dislocations involving the principal part of the malleus and incus radiography may reveal distinct changes closely corresponding to the operative findings

2 That radiographic examination is most frequently of little value in the presence of dislocations or defects localized to the incudo stapedial joint

Treatment

The aim of the treatment is to restore the function of the sound conducting mechanism between the tympanic membrane and the oval window

This may be attained by various ossiculoplastic measures the character of



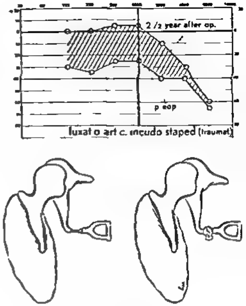


Fig. 6 Fig. 7

Fig. 6. Interposition of polyethylene tube as a columella between the tympanic membrane and the stapes footplate in a patient with inflammatory necrosis of the stapes and incus.

Fig. 7. Interposition of a bone chip between the dislocated long process of the incus and the head of the stapes in a patient with traumatic dislocation of the incus.

which to some extent depends on the conditions present in the individual cases.

A feature common to these measures is that they can be performed by a transmeatal approach through a tympanotomy in the same way as in Rosen's operation for otosclerosis. The method of reconstruction is decided upon after direct vision has revealed the true character of the lesion. The following possibilities are available:

1. *Myringo-stapedopexia* (two cases), in which the tympanic membrane is mobilized and pressed against the head of the stapes (Fig. 4).

2. *Interposition operations* in which contact between the tympanic membrane and stapes is obtained by means of an interposed medium.

(*a*) *Incus interposition* (1[illegible] cases).—If the incus is preserved, we prefer to extract this ossicle and implant it between the tympanic membrane and the head of the stapes (Fig. 5). This is a fairly simple measure, which usually results in very considerable hearing gain of a permanent character. From the studies of Hall & Rytzner (1960) we know that we need not fear that necrosis of such a freely transplanted incus will occur, and our own experience shows that the dislocated incus receives its nutrition from the mucosa of the middle ear. If the stapedial arch is intact, the incus is implanted with its body resting between the head of the stapes and the tympanic membrane. If the stapedial arch is absent, the incus may be placed as a columella between

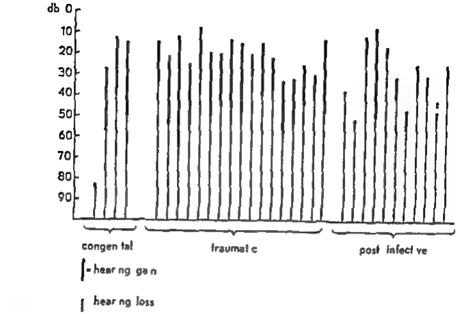


FIG 8 Results of ossiculoplastic surgery in 39 cases of ossicular chain defects

the stapedial footplate and the tympanic membrane as described by Hall & Rutzner (1957)

(*b*) *Bone interposition* (eight cases) —If the incus is absent a bone fragment of a suitable size taken from the mastoid process is placed in the same way as the incus So far our experience as to the possibilities of survival of such a free bone graft is limited

(*c*) *Implantation of foreign media* (five cases) —A short piece of polyethylene may be implanted in the same way as the bone grafts just mentioned but in our experience there is a certain risk of erosion and perforation of the tympanic membrane if the implant is resting against this structure (Fig 6)

(*d*) In the presence of a minor incudo stapedial joint separation it may sometimes be sufficient to implant a small piece of bone or polyethylene between the long process of the incus and the head of the stapes (four cases) (Fig 7) However this type of intervention is more difficult than the other interposition operations in which the incus or a bone graft is placed between the stapes and the tympanic membrane

Our follow up examinations have shown that the hearing gain obtained in all cases of successful operation has remained unchanged after the reconstruction for periods of observation of up to 2½ years (Fig 8)

Experimental Studies

We have performed a series of experiments on human temporal bones in order to study the influence of these reconstructive surgical measures on the sound transmission in the middle ear

It has proved possible to measure the sound transmission through the

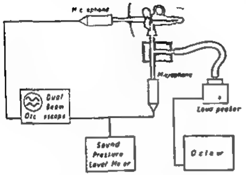


Fig 9

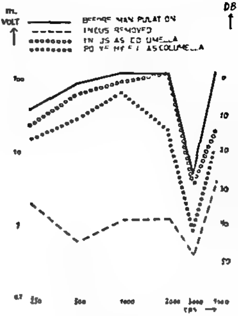


Fig 10

Fig 9 Diagram of arrangement or measuring the sound transmission in the middle ear

Fig 10 Curves showing the response produced in the external meatus under normal condition after the incus had been removed and after interposition of the incus or a polyethylene prosthesis

ossicular chain by stimulating the round window with high intensity sounds and at the same time, measuring the amplitudes produced in the external auditory canal (Fig 9) If the incus is removed, the sound conduction falls by 40–50 db We can now reproduce the reconstructive *in vivo* operations and measure the effect of these interventions Figure 10 shows that both incus interposition and implantation of a polyethylene prosthesis result in considerable hearing gains It has been of interest to ascertain that the mass of the implanted medium does not seem to be of importance, and that an increase in the mass of the sound conducting apparatus need not necessarily result in reduced transmission of high frequencies The experiments show that the position of the prosthesis is very important, and that in the most successful cases it is possible to obtain sound conduction which is very near to normal This is also in agreement with our experience in practice which has shown that we must proceed by the trial and error method under audiometric control until we have found the position of the implant which gives the best hearing

ZUSAMMENFASSUNG

Schäden in der Gehörknöchelchenkette als Ursache einer Schalleitungsschwerhörigkeit scheinen häufiger zu sein als im allgemeinen angenommen

Die Ätiologie ist traumatische Läsionen, Infektionen und weniger häufig Ent

wicklungshemmungen — Radiographie und Untersuchung des Stapediusreflexes spielen fur die Diagnose eine grosse Rolle

Durch plastische Eingriffe in der Gehorknochelchenkette ist es moglich, bedeutende Gehorgewinne bleibenden Charakters zu erzielen

Experimentelle Untersuchungen der Schalleitung im Mittelohr haben ergeben, dass bei diesen Rekonstruktionen die Moglichkeit besteht, eine Schalleitung zu erreichen, die der normalen sehr nahe liegt

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Dept of Otolaryngology
The University of Aarhus
Denmark

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CLINICAL APPLICATION OF CONTINUOUS THRESHOLD RECORDING

HENNING SØRENSEN
Aarhus, Denmark

From the University Ear Clinic (Head: Prof. H. C. Andersen, M.D.), Aarhus

Continuous threshold for a pure tone (2000 cps) was recorded in 93 normal individuals and in 355 patients with impaired hearing. In normal individuals, no threshold rise above 10 db was recorded. In pure conductive deafness the threshold also remained constant. Among patients with otosclerosis a few showed more pronounced tone decay, in the majority the threshold was constant. About half of the patients with cochlear deafness showed no tone decay, in the other half a moderate tone decay was observed. In retrocochlear deafness pronounced tone decay was recorded in 85%. Twelve patients with tumour of the cerebello-pontine angle all showed pronounced tone decay. Pronounced tone decay is considered to be indicative of functional impairment, not only of the acoustic nerve, but also of the central auditory pathways. As the test is simple to perform, it is of value in the topical diagnosis.

SCOPE OF INVESTIGATION

In perception of sound, temporal features are involved in regard to pitch as well as to loudness. If a steady tone is presented to an individual, he experiences a sensation that has a definite onset and duration. In agreement with this psycho-acoustic observation, electrophysiological studies have revealed neural events which are assumed to be correlated for both the onset of a sound stimulus, and for the steady state of condition.

The first consequence of a pure tone stimulation is a non-specific neural onset response which can be recorded at all levels in the auditory pathways. At the cortex two categories of *onset responses* differing in latency have been recorded. These onset responses are aroused by clicks, as well as by the onset of a tone, and are presumably merely the signal that a sound has occurred. *Steady state responses* to tones have been described at subcortical and cortical levels. In micro-electrode studies, it has been possible to show that single neurones respond in a stable way during the presentation of tones and a steady state frequency synchrony between the stimulating tone and the nerve discharge has been recorded at least up to 1000 cps. With presentation of a tone to the ear an auditory unit located in the cochlear nucleus or more centrally may react in three different ways. It may be aroused to greater activity, it may show less than its customary activity, or no change may be

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recorded. In the auditory nerve, however, only activation, never inhibition of the neural activity is recorded as a result of tonal stimulation, and the number of neurones that become activated is related to the frequency and intensity of the stimulating tone (Galambos 1954).

Thus, evidence has been demonstrated of the existence of two different modes of neural response related to the temporal dimension of sound. In functional impairment of the auditory nervous system the possibility exists that only one of these neural events is involved in the impairment. In psycho-acoustic experiments this can only be revealed when due regard is taken to time. In ordinary clinical audiometry, the threshold is recorded by means of short tones, which give no possibility of detecting impairment, if any, of the neural mechanism responsible for maintaining the steady state condition, which might be revealed by some sort of continuous threshold recording. Such investigations have been performed only during recent years.

However, as early as 1893, Gradenigo called attention to "an excessive functional exhaustibility in some affections of the acusticus. This exhaustibility is often produced by alterations in the inner ear, but only in affections of the auditory nerve does it reach a sufficiently marked degree to be characteristic".

Jerger (1955) performed an experiment which confirms the assumption of two different mechanisms in the perception of sound, as was observed in neurophysiological experiments. He applied a continuous pure tone (4000 cps) for 2 minutes at a sensation level of 10 db above the actual threshold to the ear. Every 6 seconds he superimposed upon this stimulus a 0.5 second short tone of the same frequency with varying intensity in order to study the difference limen for intensity by means of the tone pips. To his astonishment some patients with perceptive deafness declared that the continuous tone disappeared, whereas the tone pips continued to be heard. The tone pips continued to produce "on effects", whereas the continuous tone was not able to maintain sustained response in the auditory nervous system.

Langenbeck (1959) also demonstrated two components in the threshold shift provoked by means of bursts of white noise, viz. a rapid acting "adaptation" and a slower "fatigue" component. The adaptation reaches its peak within 0.15 seconds and recovers completely within 0.15 seconds of the cessation of the sound stimulus. Fatigue may show pathological changes along with a normal adaptation and an almost normal auditory threshold. It is believed that the two components have different physiological mechanisms.

PREVIOUS INVESTIGATIONS

Schubert (1944) compared thresholds measured by means of interrupted tones with values measured by a continuous tone. The lowest values were found with interrupted tones of decreasing intensity. The highest thresholds were obtained by measurements with a continuous tone of increasing inten-

sity In 1952 similar results were reported by Hirsh (p 102) In addition Schubert measured the time which elapsed before patients with impaired hearing could no longer perceive a continuous tone at or a little above threshold intensity Normal subjects and patients with conductive deafness could hear the tone unchanged for longer periods but in patients with perceptive deafness the tone faded away rapidly but only at frequencies above 1000 cps For frequencies above 1000 cps the average Hordauer was found to be at most 5 3 seconds in patients with perceptive deafness in combined deafness only slighly higher values were obtained

After the determination of the Hordauer he plotted against time the further increase in intensity which was required in order that the patient might still hear the tone the experimental period being extended to 20 minutes In these experiments two different types of curves were obtained

1 Curves with an initially steep increase followed by a constant threshold
2 Curves with a steady increase

In normal subjects the following factors were found to influence the curve (1) age (2) frequency (3) duration of the experiment (4) preceding exposure of the ear

At a duration of 20 minutes and frequencies above 1000 cps normal subjects revealed a threshold rise of 5 db increasing from the age of 3 years up to about 20 db A steep path of the curve was found at increasing frequency and age In elderly persons the curve differed especially in the initial steep course less in the size of the threshold shift After interruption of the tone a return to the original threshold was observed although some change was invariably seen in protracted experiments In the experiments patients with perceptive deafness and normal subjects showed no differences Patients with perceptive deafness of various aetiology (noise trauma cranial trauma congenital defect or toxic injury) revealed a short Hordauer and a steep fatigue curve with a great change in the auditory threshold up to about 25 db

Hood (1950) also stressed the importance of the design of test procedures for the investigation of on effect normality and perstimulatory fatigue which may both be recorded in the perceptive deaf suffering from end organ disease

In functional impairment of the hair cells resulting from disease or injury the response of the end organ is reduced when the stimulus level is low nevertheless the initial response (on effect) may approximate or even exceed the normal if the stimulus level is high But this response is not sustained if the stimulus is continued and indeed it may show an abnormal tendency to relapse a characteristic which again seems to be the result of hair cell disease The procedure by which Hood reveals this abnormally great adaptation *in the recruiting perceptive deaf* is a simultaneously binaural balancing technique i e performed above threshold level This makes it difficult to compare his results with others which are obtained by threshold recording A disadvantage in the binaural method is that adaptation also occurs in the test ear

Palva (1955) confirmed this finding of a change in loudness of a contin

uous stimulus, but in his experience it was not frequent, occurring in less than 20% of the cases with recruiting deafness.

By means of a Békésy audiometer de Maré & Rossler (1950) recorded a threshold shift of about 20 db in patients with perceptive deafness. The threshold shift was found to be most pronounced in the frequency range 2000–5000 cps.

The first observation of an abnormally rapid temporary threshold shift in a single case of eighth nerve tumour was reported by Reger & Kos in 1952. The threshold shift was recorded by means of a Békésy type audiometer. Since then six additional cases of eighth nerve tumours (all verified by surgery) have been seen by the same authors (1958), all of them demonstrated an excessive threshold shift for pure tones.

By means of a Békésy audiometer Lierle & Reger (1955) demonstrated the excessive threshold shift in a patient with bilateral neurinoma of the acoustic nerve. The threshold shift amounted to 60–73 db. They consider a rapid and pronounced threshold shift measured in this way as characteristic of lesions of the eighth cranial nerve.

The results obtained by Hood (1955) are at variance with this finding. By means of an ordinary audiometer he demonstrated that a normal subject or a patient with a conductive type hearing loss would detect a sustained tone at a level of 5 db above threshold for an indefinite period. On the other hand in ears with losses due to impairment of cochlear function the tone would disappear completely after a few seconds of sustained stimulation and the intensity would have to be raised as much as 30 db before a continuous response could be obtained. Thus, in agreement with the experiments of loudness shift, an abnormal perstimulatory adaptation was found in end-organ disease as a manifestation of an abnormal physiological state of the organ of Corti.

Palva (1956) tested a series of 39 ears at various frequencies with 4 minute threshold tracings by means of a Békésy audiometer. A perstimulatory threshold shift of ±5 db was considered normal. This also occurred in conductive deafness. In the non-recruiting and recruiting perceptive deafness threshold shifts of 10 db or more were recorded. It was concluded that the test did not give reliable clues to a differential diagnosis.

Carhart (1957) published the results of applying continuous threshold recording as a clinical test. Pure tones at various frequencies were used. The tone was presented at threshold intensity for a minute unless it faded away before that time. In the latter event the intensity was increased by 5 db. No rest period was allowed. Clinical cases showed varied configurations of response, and no correlation between recruitment and relapse was found. Astonishingly, some subjects with normal threshold acuity showed extreme tone decay. The author concluded that systematic study of this phenomenon might probably lead to a classification into new clinical subgroups.

In 1958 Jerger, Carhart & Lassman reported two cases of acoustic neurinoma showing pronounced relapse in continuous threshold recording. It was concluded that threshold tracing for pure tones of fixed frequency is

perhaps the only auditory test that can reliably differentiate cochlear from eighth nerve lesion.

Thomson & Hoel (1957) found certain degrees of abnormal temporary threshold shift in 10 of 15 ears with cochlear deafness due to Menière's disease or toxic lesion of the labyrinth. However, they reported that a much severer threshold shift was present in three out of a group of seven patients with retrocochlear lesions.

Cioce & Pestalozza (1958) compared various audiological tests, including the exhaustion time due to continuous stimulation at threshold levels. A total of 30 patients with perceptive deafness were studied by continuous threshold recording. The authors reported that the examination for recruitment was made by Fowler's test in the presence of unilateral impairment of hearing, while Reger's or Luscher's test was used in patients with symmetrical hearing loss. Among the 30 patients, pronounced tone decay was observed in 16: three of these had partial recruitment and nine definite recruitment, while recruitment was absent in the remaining four. Thus this study did not reveal any correlation between recruitment and tone decay.

A certain amount of tone decay, although not pronounced, was found in 100 cases of impaired hearing due to noise injury (Dieroff 1958).

Yantis (1959) found extreme temporary threshold shifts in three surgically confirmed cases of tumour of the cerebello-pontine angle, whereas a threshold shift of limited extent was found in cochlear deafness. A total of 13 abnormal ears were examined with continuous tones presented by means of a clinical audiometer and by means of an automatic audiometer. A threshold shift demonstrated by means of the ordinary audiometer was not always represented in the automatic recording.

Feldmann (1960), using a monaural method of noise audiometry to measure the adaptation during stimulation in 100 cases of perceptive deafness, found pathological auditory adaptation in the ganglionic type, but not in the hair cell type.

From the papers cited above it appears that:

1. The existence of two different neural responses, viz. on-effect response and sustained response, has been demonstrated neurophysiologically as well as in psychoacoustic experiments.

2. Functional impairment may involve either one or both of these responses. Impairment of sustained response may be found in patients with normal pure tone audiograms.

3. The least complicated and most reliable method at our disposal in investigating the impaired sustained response is continuous threshold recording by means of an ordinary pure tone audiometer.

4. Impairment of sustained response has been demonstrated in cochlear as well as in retrocochlear lesions, but seems to be most pronounced in lesions of the eighth nerve.

5. When present, tone decay is most pronounced at frequencies above 1000 cps, whereas for clinical purposes it will be sufficient to apply one high frequency

PERSONAL INVESTIGATIONS

The present paper deals with the clinical application of continuous threshold tracing. The purpose has been to investigate the amount of threshold shift by continuous threshold stimulation in a number of normal individuals and in various forms of impaired hearing, in order to contribute to the clarification of the characteristics of the phenomenon of tone decay. In addition the possible usefulness of continuous recording in clinical diagnosis of the site of a hearing impairment might be evaluated. A comparison of the test with other tests usually applied in recruitment determination has been performed, and the test has been used in cases of otosclerosis in order, if possible, to obtain information of the amount of nerve deafness present in such cases, which might be of value in determining whether a given case meets the indications for surgical intervention.

METHOD

By means of an ordinary audiometer (M. P. Pedersen) with a maximum output of 115 db re normal human threshold, the threshold for a pure tone of a frequency of 2000 cps is recorded. After the determination of a threshold, the same tone is applied continuously at threshold intensity for 90 seconds, unless it fades away within that time; in that case the intensity is increased by 5 db without interrupting the tone. The procedure is repeated until the tone can be heard at the same intensity level for 90 seconds, or until the maximum output of the audiometer is reached. The threshold was not traced for more than 7 minutes except in a few cases. It is important that the tone is not interrupted. If necessary, the contralateral ear is masked by white noise.

The result of the test is recorded graphically, the threshold being plotted against time. In principle, the curve follows three different patterns (Fig. 1).

I. The threshold remains constant within 10 db.

II. The threshold increases more than 10 db during the first 1–3 minutes and then remains constant.

III. The threshold increases continuously. In this case the threshold rise may be more or less rapid.

I. Control Series

As a basis for the evaluation of pathological cases, a total of 93 normal subjects were studied. The subjects in this control series were normal-hearing healthy individuals, mostly doctors, nurses and other members of the hospital staff. In addition, a number of persons over 80 years living in a home for the aged were studied. On the basis of the past history and otoscopy, all persons who suffered, or had suffered, from diseases of the middle ear were excluded.

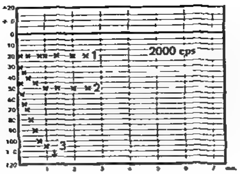

Fig. 1. Three different paths of continuous threshold recording, intensity in db, plotted against time.

An ordinary pure tone audiogram was recorded, and all subjects with hearing loss exceeding the norm for their age were excluded. The age and sex distribution of the control series appears from Table 1.

In the age group up to 60 years, all the subjects could continuously hear the tone (2000 cps) at threshold intensity, or after the threshold had been increased by maximally 10 db. Thus they all fall within type I.

The control series comprises a total of 30 individuals over 60 years, nine of these revealed tone decay of type II (maximally 20 db), following which the threshold remained constant. Cerebral arteriosclerosis was disclosed in three of these nine subjects.

The results show that one must expect a somewhat greater tone decay in about one third of individuals over 60 years than is found in the younger age groups, in which a tone decay exceeding 10 db was never observed.

II. Impaired Hearing

A total of 355 patients with hearing impairments of varying aetiology were studied during admission to Aarhus Kommunehospital. After history taking and a general physical examination careful investigation of the ears, nasal

Table 1. *Age and sex distribution of normal individuals*

Age in years	Women	Men	Total
20–30	17	10	27
31–40	5	7	12
41–50	8	3	11
51–60	6	7	13
61–70	6	11	17
71–80	3	6	[illegible]
>80	2	2	4
Total	47	46	93

cavity, pharynx, nasopharynx and larynx was performed. If anomalies of the tympanic membranes were suspected, otoscopy was supplemented by ear microscopy. In nearly all cases radiographs of the temporal bones were taken, often supplemented by tomography.

In all cases an ordinary audiogram with air and bone conduction was recorded. Rinne & Weber's test were performed by means of tuning fork and audiometer.

Examination for recruitment was performed by Fowler's binaural balance test with alternating short tones or, in cases with symmetrical hearing loss, by Reger's monaural test. In a large number of patients the recruitment test was supplemented by a recording of the stapedius reflex, which according to Metz (1952), Jepsen (1955), Thomsen (1958) and Ewertsen, Filling, Therkildsen & Thomsen (1958) must be considered to be an indicator of the presence of recruitment, and which may also give information as to fixation of the stapes.

All patients were subjected to tests for vestibular function, comprising tests for spontaneous and positional nystagmus and quantitative caloric test by the method of Hallpike & Fitzgerald. In some cases the duration of post-rotatory nystagmus was also recorded.

In patients with perceptive deafness great importance was attached to a careful neurological examination. In most cases an electro-encephalogram was recorded. When neurological abnormalities were demonstrated, the examination was extended to comprise carotid arteriography and sometimes pneumo-encephalography. Some of the neurological diagnoses, especially intracranial tumours, were later confirmed by operation.

On the basis of the case histories and these examinations the patients were classified under certain diagnoses; these diagnoses will be discussed later.

All patients with impaired hearing are listed in Table 2, grouped according to diagnosis. This table also contains information of the magnitude of the tone decay. Types I, II and III refer to the path of the curves as shown in Fig. 1.

Pure tone Conductive Deafness

A total of 20 patients with purely conductive deafness, due to various forms of otitis or sequelae thereof, were studied. This group showed good agreement with the control series, since all the patients except one had a constant threshold within 10 db, i.e. showed a curve of type I. The only exception was a man aged 18 with chronic otitis media, who revealed a threshold rise of 1[illegible] db, after which the threshold remained constant.

Otosclerosis

This gr[illegible]nsisted of 102 patients. In the vast majority of cases the diagnosis w[illegible]nfirmed by operation. Among these patients 83 revealed a normal c[illegible]f the threshold curve, nine showed a slight threshold shift

TABLE 2. *All the patients grouped according to diagnosis and type of tone decay. The three main groups are conductive deafness, otosclerosis and perceptive deafness*

Diagnosis	Threshold tone decay: Type I	Type II				Type III					
	Normal	15–20 db	25–30 db	35–40 db	45–50 db	25–30 db	35–40 db	45–50 db	over 50 db	Total	
Otitis media catarrhalis	7									7	
Otitis media adhaesiva	3									3	
Luxatio et dislocatio in cu lis	1									1	
Otitis media sequelae	4									4	
Otitis media chronica	4	1								5	
Conductive deafness											20
Otosclerosis	83	9	6				1	2	1	102	102
Morbus Menière	34	20	5	1					1	61	
Morbus Menière atyp	16	12	4		1	2	1			36	
Neurolabyrinthopathia traumatica (acoustic trauma)	[illegible]			1						6	
Neurolabyrinthopathia professionalis	2	3	1							6	
Neurolabyrinthopathia posttraumatica	4	3	1					2	1	11	
Neurolabyrinthopathia congenita	3	2	1				2	1		9	
Neurolabyrinthopathia hereditaria	2							1		3	
Neurolabyrinthopathia vascularis	7	8	1	1				2	1	20	
Neurolabyrinthopathia senilis	6	1	1							8	
Neurolabyrinthopathia toxica	2	1	1							4	
Neurolabyrinthopathia postinfectiosa	[illegible]	5	2				1	2	1	20	
Neurolabyrinthopathia typus incertus	[illegible]	2	4		1	3	[illegible]	3	9	37	
Tumor anguli cerebello pontineus							3	3	6	12	
Perceptive deafness	99	57	21	3	2	5	13	11	19		233
Total										355	355

and in six the threshold had to be increased by maximally 25–30 db after which it remained constant. A normal path of the curve was thus found in 81 % of the cases, while 15 % showed a curve of type II with a maximum threshold shift of 30 db.

In four patients with otosclerosis pronounced tone decay with curves of type III was observed in one of them the threshold rise amounted to more than 50 db These four patients were women aged from 41 to 57 years In three the case histories were characteristic of otosclerosis but one had also attacks of gyratory vertigo nausea and vomiting All four revealed pronounced tone decay in only one ear In all four cases tympanotomy was performed on the affected ear which revealed that the stapes was fixed by otosclerotic foci the hearing improved after mobilisation of the stapes The abnormal tone decay was the only feature in which these patients differed from the remaining patients with otosclerosis

A study of the relationship between the magnitude of the nerve deafness measured by bone conduction and that of the tone decay did not show any correlation The most pronounced tone decay was found in an ear with a bone conduction threshold of 20 db while some patients with bone conduction thresholds of about 60 80 db showed no decay at all

Perceptive Deafness

1 Clinical series

All patients with perceptive deafness (233) are grouped according to diagnosis in Table 2 The patients in this group had hearing losses which were equally pronounced for air and bone conduction

The largest subgroup consists of 97 patients with *Meniere s disease* including 61 typical cases with unilateral hearing impairment associated with recruitment tinnitus and attacks of gyratory vertigo nausea and vomiting

A diagnosis of *atypical Meniere s disease* was made in 16 cases because the syndrome was not fully developed the vertigo was less characteristic some had no tinnitus and others had bilateral impairment of the hearing In five of these patients in whom the clinical picture was otherwise characteristic recruitment could not be demonstrated for which reason they are listed in this group

A group of 124 patients with perceptive deafness may be divided into a number of aetiological subgroups

The subgroup of *neurolabyrinthopathia traumatica* consists of six patients with impaired hearing referable to reports of guns or explosions Under the diagnosis of *neurolabyrinthopathia professionalis* are listed six patients with impaired hearing due to work in surroundings with a high noise level Patients with hearing loss following severe head injuries (11 cases) were grouped under the diagnosis of *neurolabyrinthopathia posttraumatica*

The subgroup of *neurolabyrinthopathia vascularis* comprises a total of 20 patients with perceptive deafness which was assumed to be related to vascular disease Three patients had arterial hypertension eight suffered from cerebral circulatory insufficiency six from cerebral arteriosclerosis and three had other vascular disorders

Under the diagnosis of *neurolabyrinthopathia postinfectiosa* are listed 20

patients with perceptive deafness following infectious diseases viz enceph alitis 11 cases influenza 5 injury to the labyrinth referable to otitis media 3 and purulent sinusitis 1

Finally there is a group of 37 patients in whom the pathogenesis of the hearing impairment could not be definitely established these are listed under the diagnosis of *neurolabyrinthopathia typus incertus* In 19 of these patients it was not possible to find any clue to the disease while the remaining 18 all had another affection which might possibly be related to the auditory im pairment although no definite causal relationship could be demonstrated These affections were benign or malignant intracranial tumour 7 cases ac romegaly 2 pronounced oxycephalia 2 epilepsy 2 diffuse neurological disease with severe functional impairment 3 hemiparesis 1 and myeloid leukaemia 1

The last subgroup comprises 12 patients with *tumour of the cerebello pon tine angle* Eight of these had a neurinoma of the acoustic nerve seven were confirmed by operation The eighth patient suffered from neurofibromatosis (Recklingshausen) accompanied by severely impaired hearing abolished vestibular function and delated porus acusticus internus Operation revealed an epidermoid cyst of the cerebello pontine angle in one case Three other patients had symptoms of a tumour of the cerebello pontine angle two of these were operated upon and the operation in both cases revealed a malig nant glioma of the angle between the pons and the cerebellum

2 *Tone decay in patients with perceptive deafness*

Table 3 shows the type and degree of tone decay in the various subgroups of perceptive deafness In the total series of patients with perceptive deafness the first and last subgroups viz Ménière s disease and tumour of the cere bello pontine angle are the most well defined especially with regard to the localisation of the affection for which reason mention is first made of these diseases

(*a*) *Ménière s disease* is a disorder which is localised in the cochlea Among the 61 patients with typical Ménière s disease i e unilateral hearing loss tinnitus and attacks of gyratory vertigo 34 (or 56%) showed no tone decay while 26 (or 43%) revealed tone decay of type II the maximum threshold shift being 35 db Thus less than one half of the patients with typical Mé nière s disease differed in this test from the normal series A typical course of the curve in a patient with Ménière s disease is shown in Fig 2

Only one patient showed pronounced relapse of type III

It was a woman aged 50 who for three years had suffered from persistent left side tinnitus For two years the hearing in the left ear had steadily deteriorated and during this period there had been three attacks of violent gyratory vertigo nausea and vomiting In addition to a moderately severe left sided hearing impairment of perceptive type with recruitment and reduced caloric response in the left ear electro encephalography showed a marked difference between the two sides which aroused

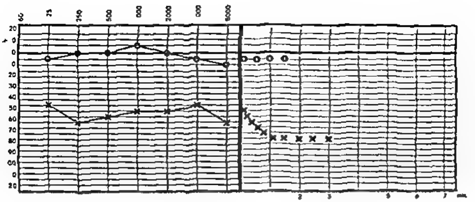

FIG. 2. Audiogram and curve for tone decay in a patient with Ménière's disease (No. 170). × left ear. O right ear.

suspicion of abnormal conditions in the right occipital region. However, pneumo-encephalography did not reveal any abnormalities. It must be assumed that some relation existed between the abnormal electro-encephalogram and the symptoms of the patient.

(*b*) *Tumour of the cerebello-pontine angle* gives rise to perceptive deafness because of injury to the acoustic nerve. This subgroup comprises 12 patients with definite retrocochlear hearing loss. *In all these patients pronounced tone decay of type III was disclosed.* This was also true of a patient with neurinoma of the acoustic nerve who showed considerable recruitment. In most cases the intensity had to be increased to the maximum capacity of the audiometer within 1–2 minutes. A typical case is illustrated in Fig. 3. Such a rapid fall is considered to be typical of a neurinoma of the acoustic nerve (Jerger, Carhart & Lassman, 1958). However, one case revealed tone decay which, although considerable, did not by far occur so rapidly (Fig. 4). This case was also *one of surgically confirmed neurinoma of the acoustic nerve*.

In one patient with bilateral acoustic neurinoma and severe hearing loss no tone decay could be demonstrated. However, the condition of the patient was so poor and her statements so uncertain that it cannot be concluded from this case that tone decay is not invariably present. After unilateral operation the patient's condition improved, so that pronounced tone decay could be revealed in the other ear.

The investigations in patients with hearing loss of unquestionable localisation—conductive type (middle ear), typical Ménière's disease (labyrinthine), tumours (retrolabyrinthine)—thus gave the following results. In the presence of conductive hearing loss (20 cases), tone decay of type I was present in 19 and of type II in one. In typical Ménière's disease (61 cases), tone decay of type I was present in 34, of type II in 26, and of type III in one. The patients with tumour of the cerebello-pontine angle (12 cases) all showed tone decay of type III. These results are in favour of the assumption that the demonstra-

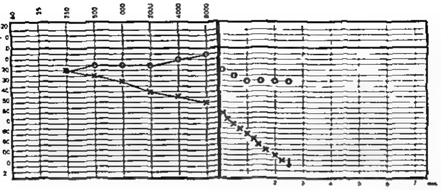

Fig 3 Audiogram and curve for tone decay in a patient with neurinoma of the acoustic nerve (No 299)

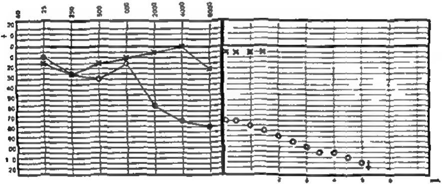

Fig 4 Slow tone decay in a patient with neurinoma of the acoustic nerve (No 297)

tion of pronounced tone decay (type III) suggests that a retrolabyrinthine lesion is the cause of the hearing defect

(*c*) *Hearing loss of uncertain origin* As appears from Table 2 the study of this subgroup resulted in highly variable findings Tone decay of type I corresponding to the results from the normal series, was disclosed in 65 cases Tone decay of type II corresponding to the findings in Ménière's disease, was revealed in 57 cases and tone decay of type III, corresponding to the results in patients with tumour of the cerebello pontine angle was found in 38 cases Of these last 38 patients not less than 21 were represented in the sub group with neurolabyrinthopathia typus incertus (of the 37 patients in this sub group 21 had tone decay of type III) In all these cases of perceptive deafness examination for recruitment was performed and on the basis of the results of this examination the patients listed in Table 3 were divided into three groups with recruitment without recruitment and uncertain result This classification shows that *tone decay of type III* was not demonstrated in patients with neurolabyrinthopathia accompanied by recruitment In neurolabyrinthopathia without recruitment tone decay of type III was pres

TABLE 3 *Type and amount of tone decay in the various subgroups of perceptive deafness*

	Recruitment									
	Present			Absent			Uncertain			
	Tone decay type			Tone decay type			Tone decay type			
Diagnosis	I	II	III	I	II	III	I	II	III	Total
Morbus Ménière	[illegible]	25	1				2	1		61
Morbus Ménière atyp	7	9		2		3	7	8		36
Neurolabyrinthopathia traumatica	2	1					3			6
Neurolabyrinthopathia professionalis	1	3					1	1		6
Neurolabyrinthopathia posttraumatica		3				3	4	1		11
Neurolabyrinthopathia congenita	[illegible]					3	1	3		9
Neurolabyrinthopathia hereditaria							2		1	3
Neurolabyrinthopathia vascularis	3	8		1	1	1	3	1	2	20
Neurolabyrinthopathia senilis		1					6	1		8
Neurolabyrinthopathia toxica	1	1			1		1			4
Neurolabyrinthopathia postinfectiosa	4	5				4	5	2		20
Neurolabyrinthopathia typus incertus	2	2		2		13	5	5	8	37
Total	51	58	1	5	2	27	40	23	11	221

ent in 27 of 34 cases, i.e. in 79 %. If the Fowler test is replaced by a recording of the stapedius reflex as the method for localisation of the cause of the hearing loss, it is seen, as appears from Table 5, that the stapedius reflex was present in a total of 76 out of 124 patients who were studied; of these patients 75 had tone decay of type I or II, while only one (the aforementioned patient with Ménière's disease) had pronounced tone decay. Among the 46 patients in whom the stapedius reflex could not be elicited, 24 had pronounced tone decay of type III and 22 tone decay of type I or II. Of these patients four, three, and three of types I, II and III respectively had cicatricial tympanic membranes, which may explain why the stapedius reflex could not be elicited. The results of these examinations argue in favour of the assumption that the cause of the neurolabyrinthopathia in the cases in which tone decay of type III was demonstrated was a retrocochlear affection. In order, if possible, to disclose further evidence in support of this assumption an analysis was performed of the occurrence of neurological findings suggestive of intracranial

TABLE 4 *Relation between the results of Fowler's binaural balance test and the type of tone decay*

Recruitment	Tone decay Type I	Type II	Type III	Total
Present	54	58	2	114
Absent	5	2	35	42
Uncertain	7	8	2	17
Total	66	68	39	173

TABLE 5 *Relation between the results of the stapedius reflex test and the type of tone decay*

Stapedius reflex	Tone decay Type I	Type II	Type III	Total
Present	48	27	1	76
Absent	16	6	24	46
Uncertain		2		2
Total	64	35	25	124

lesions in these patients, including abnormalities in the electro encephalogram Of the 65 patients with tone decay of type I, 16 (or 24%) had neurological ab normalities, among 57 patients with tone decay of type III, changes were present in 13 (or 22%) Among the 38 patients with tone decay of type III there were 24 (i e 63%) who had neurological disorders These disorders were either vascular changes or intracranial tumours

The most frequent occurrence of neurological disorders in patients with pronounced tone decay as compared with patients with no or only slight tone decay supports the assumption that pronounced tone decay is suggestive of an impairment of the acoustic nervous system In patients with an intra cranial tumour, involvement of the acoustic nerve through a pressure in crease or displacement of the nerve may give rise to the pathological tone decay, but in the presence of diffuse affections, such as multiple sclerosis, en cephalitis or arteriosclerosis it must be assumed that the increased tone decay is due to functional impairment of the central auditory pathways

Lesion of the Acoustic Nerve

An example showing that pronounced tone decay may occur as a conse- quence of injury to the acoustic nerve which is not reflected in the pure tone audiogram is given below

The patient was a woman aged 38, who for about 18 months had suffered from attacks of gyratory vertigo with nausea and vomiting and fluctuating hearing im

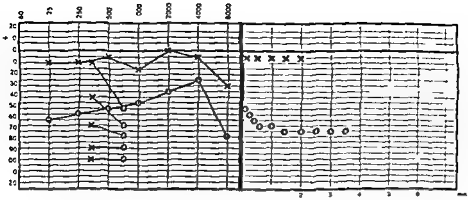

FIG. 5 a

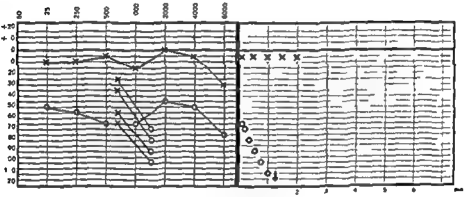

FIG. 5 b

FIG. 5. Audiogram with Fowler's test and curve for tone decay in a patient with Ménière's disease (No. 177). a: before division of the vestibular nerve; b: after division of the vestibular nerve.

pairment and tinnitus in the right ear. Audiometry revealed right-sided moderately severe perceptive deafness with recruitment. Tone decay of type II amounted to 20 db. Owing to the attacks of severe vertigo, division of the right vestibular nerve was performed, following which the attacks disappeared, while the hearing remained largely unchanged. Strangely enough, recruitment could no longer be demonstrated by Fowler's test, nor could the stapedius reflex be elicited by vigorous sound stimulation in the right ear. Postoperatively, the patient displayed pronounced tone decay of type III, exceeding 50 db (Fig. 5).

The pronounced postoperative tone decay in this patient was presumably due to a minor lesion (oedema?) of the acoustic nerve which had not been so pronounced that it was reflected in the pure tone audiogram, but which had nevertheless given rise to impaired function of the nerve. The explanation of the postoperative absence of recruitment may be that only nerve fibres from the inner hair cells had been injured, which is in harmony with the fact that the threshold remained unchanged.

Owing to attacks of vertigo, division of the vestibular nerve was also per-

formed in four other patients with Ménière's disease. In these patients the hearing also remained largely unchanged after the operation, but recruitment and stapedius reflex were still present, and none of them showed pronounced tone decay.

DISCUSSION

The present investigation has shown that pronounced tone decay is indicative of functional impairment of the acoustic nerve or the central auditory pathways, and that the method is clinically applicable in the topical diagnosis. Obviously, the results of the examination must be considered in relation to other findings in the clinical evaluation of the condition of the patient.

The test is simple and easy to perform. No special apparatus is required. In the majority of the patients it does not cause any difficulties. However, a few patients must be excluded because they report that they can hear the tone after it has been interrupted—a control measure which must therefore always be taken.

In the cases in which tone decay is present most patients report that any sound sensation has ceased, but some patients state that they have a sensation of noise in the ear when they can no longer hear the tone. In such cases only the perception of pitch is used as an indicator, whereas the persistence of noise is disregarded.

In all patients with tone decay, the threshold of hearing returns to the pre-stimulatory level within half a minute after the interruption of the tone. It seems impossible that the measured threshold shift should be due to fatigue in the ordinary sense of this word, i.e. decreased excitability due to preceding function, since such a decrease in excitability after stimulation by a high-intensity sound, both in animal experiments and in psycho-acoustic investigation, has a duration which is equal to or greater than the stimulus duration.

It is important that the tone is not interrupted at any time during the examination, since even a very brief interruption or fluctuation in the intensity will give rise to a new on-effect. An ordinary audiometer with a constant tone must therefore be considered to be more suitable in the test than a *Békésy audiometer. Of other possible sources of error which may give rise* to tone decay the following must be considered:

1. Mental exhaustion or torpor. This source of errror can be excluded in the cases in which the tone decay is unilateral, or in which it is dependent on the frequency. In addition, pethidine experiments seems to show that torpor does not give rise to tone decay.

Bilateral tone decay might conceivably be due to failure of concentration because of general mental debility, exhaustion or torpor. In order to study tone decay in patients with poor concentration the test was performed in a total of five normal hearing patients (with pulmonary disease) before and after pethidine injection. It appeared that the threshold remained unchanged after administration of large doses of pethidine (100–150 mg).

2. Tinnitus, especially if it has a frequency very near to that of the test tone, might be conceived to mask the test tone.

In the clinical series there were a total of 156 patients with tinnitus; among these pronounced tone decay was present in 75, i.e. less than 50%. In particular tinnitus was present in many patients with otosclerosis, in which group there were few patients with more distinct tone decay than in the control series. Only 26 patients with otosclerosis had no tinnitus, including two with tone decay.

As an important result of the investigation it must be emphasised that all patients with tumour of the cerebello-pontine angle showed tone decay of type III, and the method must therefore be regarded as a very suitable audiological test for the disclosure of lesions of the acoustic nerve.

In cases with intracranial tumours an indirect affection of the acoustic nerve is conceivable, due either to increased pressure or to a displacement of the nerve, but in diffuse neurological disorders without space-occupying lesions or increased pressure (such as encephalitis or arteriosclerosis) the causative mechanism must be of a different nature. The cause must then presumably be sought in functional impairment of the central auditory pathways in the pons or centres at a higher level.

In cochlear affections pronounced tone decay is an exception to the rule. Most frequently tone decay is absent, and the second commonest occurrence is tone decay of type II. In cochlear affections tone decay is possibly an expression of incipient nerve degeneration.

A theoretical explanation of the pathological threshold tone decay may be based on our knowledge of the physiology of the acoustic nerve and the central auditory pathways. It must be remembered that loudness for a certain frequency is a function of the total number of nerve impulses per unit of time, which is determined by the number of fibres activated and the number of nerve impulses in each fibre.

According to Wever's volley theory, the frequency of the stimulating sound *is produced in the total output of the nerve impulses by rotation of* activity of a group of fibres. The individual nerve fibres have different upper frequency limits, thus only relatively few fibres are at disposal for high frequencies at low intensity, and any lesion of the nerve will further decrease the number, so that we may imagine that the number is not sufficient for continuous rotation. If in such a case the intensity is increased, this will result in an increase in the number of *active fibres, but each fibre will also* have to fire more frequently, and the reinforced group will still be incapable of continuous reproduction of the frequency, so new fibres must be activated by increasing the intensity, and so on. In case of a prolonged refractory period of the nerve fibres, the entire nerve will be unable to maintain the steady state of conduction. The acoustic nerve is a bottle-neck to central hearing, as *the smallest number of fibres are at disposal here (30 000). It will therefore* be understood that pronounced tone decay principally occurs in lesions of this nerve.

However, more knowledge of the patterns of auditory nerve impulses is necessary before we may be fully able to understand the mechanism of tone decay.

ZUSAMMENFASSUNG

Laufende Reinton Hörschwellenmessungen (2 000 Hz) wurden bei 93 normalen Personen und 355 schwerhörigen Patienten durchgeführt. Bei normalen Personen wurde keine Hörschwellenerhöhung von mehr als 10 db beobachtet. Bei reiner Mittelohrschwerhörigkeit wurde die Hörschwelle ebenfalls unveränderlich befunden. Unter Patienten mit Otosclerosis zeigten einige ausgesprochenere Schwellenerhöhung, bei den meisten war die Hörschwelle unveränderlich. Etwa die Hälfte der Patienten mit Innenohrschwerhörigkeit zeigten keine Schwellenerhöhung, bei der anderen Hälfte wurde eine mässige Schwellenerhöhung befunden. Bei zentral bedingter Schwerhörigkeit wurde in 85 % eine ausgesprochene Schwellenerhöhung beobachtet. Zwölf Patienten mit Kleinhirnbrückenwinkeltumoren zeigten alle ausgesprochene Schwellenerhöhung. Eine ausgesprochene Schwellenerhöhung betrachtet man als ein Zeichen einer funktionellen Störung nicht nur des Gehörnerves, sondern auch der zentralen Gehörbahnen. Da der Test sehr leicht ausführbar ist, ist er aus grosser lokalisierungsdiagnostischer Bedeutung.

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The University Ear Clinic, Aarhus, Denmark

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POLYCHONDRITIS

Report of the First Danish Case

FINN JENSEN
Copenhagen, Denmark

From the Department of Medicine (Head: A. Harrestrup Andersen, M.D.), Sankt Lukas Stiftelsens Hospital, Copenhagen

The first Danish case of polychondritis is reported. The symptomatology of the disease is described and its possible aetiology, pathogenesis, differential diagnosis, and treatment are discussed.

Polychondritis is an extremely rare disease with a varied symptomatology. It is due mainly to affection of cartilaginous tissue, but other organ systems, e.g. the eyes and myocardium, are usually involved as well.

Polychondritis was observed in a patient admitted to the Medical Department of Sankt Lukas Stiftelsens Hospital, Copenhagen, in October–December 1958. The diagnosis was not made until the patient had been discharged, when the paper by Pearson *et al.* appeared (6). From the literature these authors collected 10 patients with polychondritis and added two of their own. Searching the literature I succeeded in finding yet another two typical cases (3, 4), although the diagnosis had not been made by the respective authors. No cases appear to have been reported from Denmark.

CASE REPORT

Our patient (case record 718/58) was a 43 year old woman who had been in good health apart from repeated attacks of tonsillitis. In particular, she had never had tuberculosis. In 1946 she had bilateral tonsillectomy, and thereafter she had no E.N.T. trouble until the present disease, which set in about 6 months before admission in the form of influenza-like symptoms followed by persistent fatigue. She had short periods of fever, and during the last three months before admission she had noticed swelling of both auricles, which became bluish, painful and rather soft, with scaling of the skin. During the last month pain on swallowing, hoarseness, night sweats, lack of appetite, weight loss, chest pain, and a dry cough. Out-patient laryngoscopy was said to have shown no abnormalities. In addition, the patient was complaining of pain in the metatarso-phalangeal joints of both big toes and the inter-phalangeal joints of the little and ring fingers of the left hand. These

FIG. 1. The patient's right external ear 2 years after the onset of the disease.

joints were swollen, showing reddish purple discoloration of the overlying skin. Several courses of penicillin had proved ineffective.

Physical examination

On admission the patient was tired, anaemic, emaciated (weight 43.8 kg, height 158 cm), and had a pulse rate strikingly fast compared with the temperature (96/37.8°C).

External ear. Both auricles, except the lobules, were somewhat enlarged by soft cutaneous and subcutaneous infiltration. No eczema, but a reddish cyanotic hue. The swelling had obliterated the scapha and reduced the external meatus to a narrow slit. The aural cartilages were abnormally soft to palpation and tender.

Pharynx. Both tonsils had been removed. No acute mucosal changes. Indirect laryngoscopy showed mild laryngitis. On the neck a few moderately enlarged lymph nodes.

Chest. There was swelling of the junction between the ribs and the costal cartilages, and the cartilages were tender.

Limbs. Mild swelling of the metatarso-phalangeal joints of the big toes, more pronounced swelling of the inter-phalangeal joints of the little and ring fingers of the left hand, which were also rather tender. Otherwise the physical examination showed no abnormalities.

Laboratory findings. E.S.R. 119 mm/hour. Hb 70%. R.B.C. 3.52 mill., colour index 1.01. W.B.C. 18,100. Differential count: rod-shaped granulocytes 2%, segmented granulocytes 85%, lymphocytes 3%, and monocytes 10%. Sternal

Fig. 2. Photomicrograph of biopsy from the auricle. Perichondrium showing an ample content of capillaries and pronounced round cell infiltration in the deeper layers. At the bottom an ill defined border against the cartilaginous zone.

bone marrow changes like those seen in infections, allergic conditions or Hodgkin's disease (sd. H. Gormsen). Serum iron 0.045 mg/100 ml, serum uric acid 5.5 mg/100 ml. W.R. and gonococcal reaction negative. Mantoux (10 tuberculin units) +8 mm, sputum: no Tb. in smears or on culture, no tumour cells. Total protein in the serum 6.9 g/100 ml. Electrophoresis revealed a moderate reduction of albumin and α_1, slightly elevated α_2 and γ globulin values. E.C.G.: tachycardia, but no other abnormalities. Other laboratory tests showed normal conditions. X-rays of the lungs and heart failed to show any abnormalities (on three occasions). X-rays of the ankle and toe joints: mild deforming arthritis of the first metatarso-phalangeal joint on both sides. Left little finger: distinct halisteresis, but no abnormalities of the interphalangeal joints.

Microscopic examination of a biopsy from the aural cartilage showed increased cornification on the surface of the skin. The corium was a little over medium thickness, of normal structure but the seat of minimal perivascular round cell infiltration and mild oedema. The greatly thickened perichondrium was superficially of a loose structure, furnished with ample capillaries, the seat of more severe oedema but less round cell infiltration. In the deeper layers of the perichondrium, on the other hand, a dense fibrillar and cellular tissue severely infiltrated with inflammatory cells, most of which were plasma cells. The junction between the perichondrium and the hyaline

FIG. 3. The patient's appearance today. Note the saddle nose and a soft, thickened, somewhat flabby auricle.

cartilage zone was irregular and ill defined. The stainability of the cartilaginous tissue was reduced, but the cells were normal and well preserved. The inflammatory cells deep in the perichondrium continued irregularly in small strands into the cartilaginous tissue. Microscopic diagnosis: severe exudative and proliferative chronic perichondritis encroaching on the cartilaginous tissue and deeper layers of the skin (sd. Sv. Petri).

The patient's main complaints were fatigue, joint pain, a dry cough and a feeling of tension in the chest.

The diagnosis was uncertain. Since the condition was interpreted as a systemic disease, steroid treatment was instituted with Meticorten 5 mg three times daily and corticotrophin 25 int. units at intervals of a few days. This immediately normalized the temperature and the joint pain decreased. The swelling of the ears diminished and the cough subsided. Her voice, however, remained just as hoarse and deep. Despite steroid medication the disease process was still active, as swelling of the bridge of the nose at the junction of bone and cartilage appeared. When this swelling subsided, the bridge of the nose collapsed, leaving a marked saddle nose.

During the past two years the patient's condition has remained practically unchanged. Her main complaint is fatigue. The hoarseness and nasal deformity are unchanged. The aural cartilages are very soft and periodically the outer ear literally droops. The swelling of the auricles has perceptibly decreased and there is no tenderness. The colour of the ears has faded from the originally bright reddish cyanotic to a pale greyish brown. At a follow-up visit a couple of months ago the E.S.R. was 33 mm/hour and X-rays showed

slight dilatation of the heart The patient is taking Ledercort® tablets (triamcinolone) 2 mg three times daily and is injected with corticotrophin 25 int units once a month The disease appears to be stationary on this dose of steroid but any attempt at reducing the dosage results in rapid exacerbation Occupationally the patient carries on with her job as book keeper in a big firm but she is so tired that she has to lie down as soon as she gets home from work

The elevated sedimentation rate and the exacerbations resulting from any attempt at reducing the steroid dose indicate that the disease is still active When considering also other authors experience of this disease the prognosis must be considered doubtful The greatest danger in these cases is respiratory infection to which the resistance is reduced partly because of the softness of the laryngeal tracheal and costal cartilages and partly because of the steroid therapy

DISCUSSION

The name of the disease has not yet been decided upon At present while its aetiology and pathogenesis remain unelucidated English speaking authors call it (chronic atrophic) polychondritis or relapsing polychondritis while German speaking authors prefer the terms polychondropathy or chondromalacia

The first case was described in 1923 by Jaksch Wartenhorst (?) and the next one in 1936 by Altherr (1) and Meyenburg (5) (same patient) Out of the 14 patients on record 5 have been men and 9 women The age at onset of the disease has ranged from 14 to 61 years usually between 30 and 40

Out of the 14 patients the disease has involved in all but 1 the outer ear in all but 1 the nose in all but 1 several joints and in all but 2 the larynx and trachea In 10 the costal cartilages have been involved and 5 patients have had symptoms from the middle ear and inner ear in the form of hearing impairment of the perceptive type in 1 even total deafness Nine patients have exhibited various ocular signs dry conjunctivitis (reminding one of Sjogren s syndrome) iridocyclitis scleritis hypotonia bulbi cataract or synechiae

The sedimentation rate may be normal but as a rule it has been greatly elevated Cardiac complications are common due to myocardial damage including tachycardia of about 100 145/minute

The course has differed within wide limits but it is characterized by remissions (spontaneous or induced by steroid medication) followed by new exacerbations Four of the patients have died the causes of death being spontaneous pneumothorax asphyxia after collapse of the softened trachea bronchopneumonia and cardiac failure

Differential Diagnosis

The diagnostic difficulties are increased by the rare occurrence of the disease and by the involvement of a number of different organ systems

The joint involvement may give rise to difficulties in differentiating the condition from rheumatic fever. In both diseases the articular symptoms are often transient and migratory. However, the antistreptolysin titre and the antistreptococcus hyaluronidase titre are always normal in polychondritis. Rheumatoid arthritis, due to its localization to the finger joints and the X-ray changes in these joints, may be reminiscent of the articular lesions of polychondritis. However, the pathology, the course and the negative streptococcus agglutination reaction militate against rheumatoid arthritis. A negative gonococcal reaction always secures the differential diagnosis against gonorrhoeal arthritis. The similarity to Sjögren's syndrome was mentioned above. The articular lesions and the ocular signs often resemble those seen in Reiter's disease, but the course as well as the absence of urethral lesion render the diagnosis of Reiter's disease unlikely. In the initial phase the articular signs in our case were suggestive of gout. However, the auricular cartilaginous lesions were easy to distinguish from tophi, and the normal blood level of uric acid soon ruled out the possibility of this diagnosis. In two cases there has been a certain similarity of symptoms with ankylosing spondylitis: 1 patient with spondylitis has had changes of the aural cartilages (1), while 1 patient with polychondritis has had involvement of the vertebral joints.

Histologically, the affection of the aural cartilages may be reminiscent of chondrodermatitis nodularis chronica helicis, but clinically there can probably be no difficulties in differentiating from this disease. In the acute phase the auricular disease may be difficult to distinguish from ordinary bacterial perichondritis, as in our case who had been treated for this reason with several courses of penicillin.

Aetiology and Pathogenesis

The aetiology is unknown. A hereditary factor seems out of the question. Infection is not likely either, since bacteria have never been cultured from the affected organs. Neither syphilis nor tuberculosis play any aetiological role. Only one of the reported cases (1) has had tuberculosis. *On the basis of repeated* chest films and the clinical findings (temperature curve, Mantoux reaction and course) it was demonstrated that the tuberculosis had set in between five and seven months *after* the onset of polychondritis. No one has advanced convincing arguments in favour of a virus infection, metabolic disorder or an endocrine disease. Numerous attempts have been made to demonstrate complement forming auto-antigens against cartilaginous tissue in the patients' blood, but without success.

The disease might be imagined to be due to alterations of an enzymic nature. By intravenous injection of the proteolytic enzyme papain, Thomas (7) produced cartilaginous changes which clinically as well as histologically were very similar to those found in human polychondritis. He demonstrated that 3 or 4 hours after injection of a few mg papain the rabbits' aural cartilages softened ... that gradually the ears would droop. This process was reversible

FIG. 4. 1A, rabbit's ears before injection of papain. 1B, 4 hours after injection of papain. 1C, 24 hours after the injection. 1D, 5 days after the injection (reproduced from (7)).

the ears regaining their normal stiffness in a couple of days. Some of the experimental animals also showed softness of the tracheal cartilages, and these rabbits succumbed to asphyxia due to tracheal collapse. Microscopic examination of biopsies from the rabbit ears, removed 4 hours after the injection of papain, showed that the greater part of the intercellular matrix of the cartilaginous tissue had disappeared and that its remaining part had lost its normal basophilia. The chondrocytes were somewhat larger and rounder than normal and were more closely arranged due to the loss of intercellular substance. These are the same changes that were found in our case and in the two cases seen by Pearson *et al.* (6).

It is still unknown whether papain or other enzymes are factors in human polychondritis. The proteolytic properties of papain have been tried in the treatment of patients with ascarides. In a few allergic subjects the substance has caused hypersensitivity reactions in the form of asthma and vasomotor rhinitis, but an effect analogous to that on the cartilaginous tissue in the rabbit has not been observed in man. Commercially, papain has been used in the food industry to make the more inferior pieces of meat tender, but our patient had not—as far as she knew—eaten papain.

Treatment

Treatment with corticotrophin and prednisolone has had an excellent symptomatic effect upon the joint affection in several cases, including ours. It has perhaps also inhibited the progression of the cartilaginous affection. The cartilaginous changes present at the commencement of steroid medica-

tion have proved irreversible The treatment has to be continued indefinitely, presumably for life. Our unfavourable experience of reducing the steroid dosage accords with that of others (6)

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ZUSAMMENFASSUNG

Der erste danische Fall von Polychondritis wird berichtet Die Symptomatologie der Krankheit wird beschrieben und ihre eventuelle Atiologie, Pathogenese, Differentialdiagnose und Behandlung werden diskutiert

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429, Strandvej, Klampenborg, Denmark

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FENESTRATION OF THE OVAL WINDOW AND INTERPOSITION

OTTO H. MEURMAN and TAUNO PALVA
Turku, Finland

From the Otolaryngological Univ. Clinic (Head: Prof. O. H. Meurman, M.D.), Turku

A total of 145 cases operated on by the authors at the Otolaryngological University Clinic in Turku are presented. The following were the most important points in the operation: intubation anesthesia, endaural incision, tympanotomy, fracturing of the crura from the footplate, total removal of the plate, sealing of the window with a graft of temporal muscle fascia, repositioning of the crura or replacement of the stapes with a polyethylene tube, and turning of the tympanic membrane and the meatal skin back into place.

The results showed that the air-bone gap closed in 89 % of all cases. In 10.3 % the gap remained from 11–20 db and in 0.7 % from 21–30 db. In 12 cases (8.2 %) hearing receded to the preoperative level. The impairment invariably occurred within the first six months of the operation. It was caused either by too short crura, which no longer formed a firm bridge between the incus and the window as the fascia graft contracted, or by reossification of the window in those cases in which it could not initially be opened completely because of the large size of the otosclerotic focus. No reossification of the window was seen in the cases in which complete opening had been possible. There were no complications in the form of deaf ears. Two late degenerations occurred.

The authors consider that fenestration of the oval window with interposition of the crura or a polyethylene tube is the best of the currently used operations for otosclerosis. Covering of the window with a graft of temporal muscle fascia is a simple and very satisfactory method.

In recent years stapes surgery has become more and more radical—a development which seems logical in view of the considerable number of non-permanent results obtained with the less radical mobilization techniques. The new techniques aim at complete removal of the otosclerotic bone together with the normal footplate areas from the oval window, and at substitution of the stapes plate by other material not subject to bony fixation.

In the United States, Shea (1956) was the first to report a case operated by the technique of removing the stapes footplate, covering the window with a graft, and interpositioning a new columella between the incus and the oval window. He has since further elaborated this technique (1958); one of the last series published (1960) consists of 154 cases—mostly patients on whom mobilization had been tried without success.

The financial support of the Sigrid Jusélius Foundation is gratefully acknowledged.

tion have proved irreversible. The treatment has to be conti[illegible] presumably for life. Our unfavourable experience of red[illegible] dosage accords with that of others (6).

ACKNOWLEDGMENTS

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ZUSAMMENFASSUNG

Der erste dänische Fall von Polychondritis wird berichtet. Die Sy[illegible] der Krankheit wird beschrieben und ihre eventuelle Ätiologie, Pat[illegible] ferentialdiagnose und Behandlung werden diskutiert.

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more was obtained in 88.8 % and a 30 db level or practically useful hearing in 72 %. In 9.2 % there was no change in hearing acuity.

With the progress of clinical studies of stapedectomy some important data were also derived from animal experiments. One important fact is that in place of the removed footplate a covering membrane grows from the endosteal mucosal layer (Bellucci & Wolff 1959) or both from the periosteal and endosteal layers (Cornelli 1959). Thus a kind of self sealing prevents open communication between the middle and inner ear spaces which if remaining might be very dangerous in all inflammatory middle ear affections. Without the stapes however the hearing in these ears would not rise to the desired level as the resulting hearing would mainly depend upon the phase differences between the two windows. This fact is also borne out by the early stapedectomy experiments of Cawthorne (1951).

Another fact which has not as yet been definitely evaluated is the effect of the vein graft upon the inner ear. Although clinical experience in human cases of otosclerosis shows that the graft is well tolerated animal experiments have shown alarming reactions. Thus Bellucci & Wolff (1960) reported that five of the six cat ears with a vein graft had shown fibrous reactions in the inner ear. In those cases where bony footplate fragments remained under the graft no fibrosis occurred in the inner ear. The areas surrounding the graft in the middle ear showed evidence of considerable fibrosis. The polyethylene tube on the other hand was tolerated without any untoward tissue reactions.

Bellucci and Wolff noted that the method of using gelfoam as an oval window graft is not without danger. In three of eight cat ears fibrous tissue reaction followed in the inner ear although the changes were not so severe as those following the use of a vein graft.

At present there is very little evidence of tissue reactions to subcutaneous tissue or adipose grafts. In a preliminary note Schuknecht *et al.* (1960) mention that this tissue persisted in cat oval windows as a viable graft covered on both sides with endothelial lining. However if dislocation of the graft into the vestibule occurred to any greater extent fibrous healing with inner ear damage resulted the changes varied from mild fibrous proliferation to total destruction of the cochlear and vestibular sense organs.

Operative Technique

For fenestration of the oval window we have abandoned local anesthesia generally used in stapes mobilization procedures. In oval window fenestration there is no need to have the patient's active co-operation for conducting auditory tests during the operation; the hearing gain is clearly predictable on the basis of the technical success of the fenestration. Furthermore general intubation anesthesia allows the operator to concentrate solely on the technical part of the fenestration. Even slight involuntary or voluntary head movements sometimes disturbing at crucial moments are entirely eliminated.

However, we use local anesthesia in the meatus for reducing bleeding which otherwise would cause unnecessary trouble when blood enters the middle ear. For this purpose 0.5 % xylocain is employed with added epinephrine or in cases of fluothane anesthesia with neosynephrine. If necessary, cautery is used to stop bleeding at specific points. Lately the patients have been kept in a slight antetrendelenburg position which has further reduced the bleeding.

The middle ear is entered via an endaural incision; we feel that this gives the surgeon a much better view into the operative field than is possible when operating through an ear speculum. After the tympanic membrane is reflected, bone is drilled away from the posterior meatal wall for obtaining good visualization of the footplate region.

The stapedial crura are fractured as close to the footplate as possible and the stapes is lifted on to the promontory away from the window. One of us (O. M.) has generally preserved the stapedius muscle intact, the other (T. P.) has generally cut it before fracturing the crura. The articulation between the stapes and incus, if possible, is left undisturbed.

We ordinarily attack the footplate at its center where the bone is thinnest: a small hole is made with a perforator and the opening is enlarged in all directions up to the rim of the oval window. The otosclerotic foci are generally thickest at both ends of the footplate and it may be difficult to remove these *in toto*. Especially the anterior end may be difficult to free because the long process of the incus is also in the way. It does not seem necessary, however, to remove it at all costs, because removal of the center and the lower pole does as such result in a large functioning window.

For creating the window, most of the straight spikes used in stapes mobilization are useful instruments. We use also the curved instruments of M. Portmann at specific points. Hitherto we have not had a microdrill at our disposal; one case in this series of 145 operations would have needed drilling as the bone was too thick to be penetrated with the perforators.

For suction, needles of various calibers are used, the smallest being reserved for suction at the opened window. Suction of as little perilymph as possible is aimed at because a definite correlation has been noted between the amount of suctioning and postoperative vertigo. If only a minimal amount of the perilymph is sucked out, the patients seldom complain of any nausea or dizziness.

When the fenestra has acquired its final size, one can clearly see the saccular macula at the bottom of the vestibule. The utricular macula is more seldom seen without shifting the microscope to the area under the facial nerve.

A piece of gelfoam is next placed on the fenestra while material is being cut for the new footplate. As a rule we use temporal muscle fascia taken through the endaural incision. In some cases plain subcutaneous tissue or fat is used for covering the fenestra.

The piece of fascia is slightly invaginated in the window and it extends somewhat over the edges in all directions. The stapes is placed back into

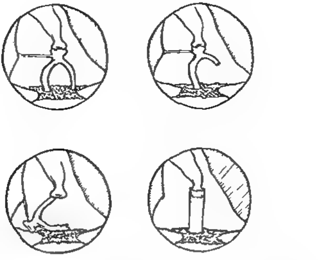

Fig. 1. Types of interposition. Either stapes or polyethylene tube can be used.

its original position, generally with one long functioning crus. It is also possible to use other positions of the stapes. If the stapes does not give good contact it is replaced with a polyethylene tube cut askew at the lower end, the upper end fitting the lenticular process of the incus (Fig. 1).

Finally Codelcort® solution is dropped into the middle ear, and the drum together with the meatal skin replaced. The meatus is filled with neomycin moistened cotton rolls. A strip of gauze is placed uppermost.

Postoperatively the patients receive penicillin 1 000 000 units on the first day and 600 000 units for the following five days by intramuscular injections. If there is vertigo, the patients are kept in bed a few days; if not, they are allowed up the following day. The meatal packing is suctioned daily, as the endaural incision gives some drainage during the first days. On the fifth day the gauze and meatal cotton balls are removed and the patients are discharged the following day. No other postoperative treatment is required.

MATERIAL AND RESULTS

The material consists of 145 operated ears. In some of these a simple mobilization had been performed previously, in others the present oval window fenestration with interposition was the first operation. The material is by no means selected. Classified according to Shambaugh, it consists of A, B and C cases; it is therefore impossible to judge the results on the basis of a single criterion. The hearing improvement in decibels is of course much bigger in A cases than in B and C cases and does not give a correct picture of the material as a whole. The same situation appears if we look only at the percentage of cases reaching the 30 db level. The postoperative air bone gap gives perhaps the most accurate picture in a heterogeneous material. Even by this means the degree of postoperative cochlear degeneration is not shown

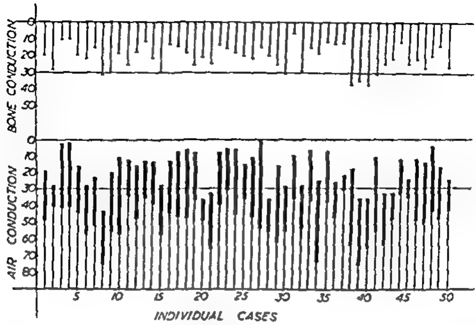

FIG. 2. Individual results in 50 cases. The lower part of the graph shows the postoperative air conduction improvement (black bars); the upper half indicates the preoperative bone conduction levels. All figures are based on the averages for 500, 1000 and 2000 cps.

Therefore we have used various ways to demonstrate the results as clearly as possible.

Figs. 2–4 present the pre- and postoperative air and bone conduction in the total material. All the tables below have been calculated on the basis of these graphs.

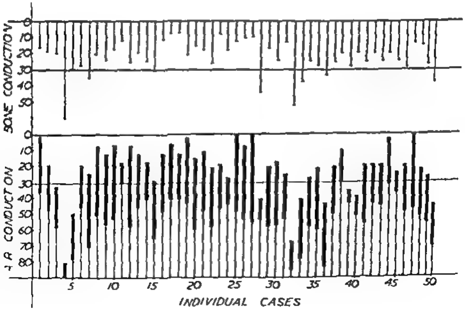

FIG. 3. Individual results in 50 cases.

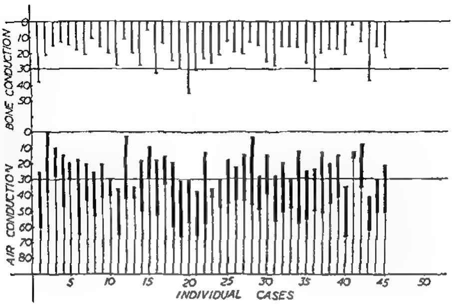

Fig. 4. Individual results in 45 cases

Table 1 shows the postoperative hearing levels expressed as a mean value of the three middle frequencies. It shows, for instance, that in 16 % of the cases the practical hearing level of 30 db was not reached. However, in 17 out of these 23 cases the air bone gap was closed. In the remaining six cases the connection between the incus and the window was not good enough.

TABLE 1. *Postoperative hearing level*

Mean value for 500, 1000 and 2000 cps

No. of cases	Hearing level (db)	Per cent
122	0–30	84.1
23	31	15.9

TABLE 2. *Hearing improvement*

Mean value for 500, 1000 and 2000 cps

No. of cases	Improvement (db)	Per cent
9	0–10	6.2
23	11–20	15.9
50	21–30	34.5
43	31–40	29.6
18	41–50	12.4
2	51	1.4

TABLE 3. *Postoperative air bone gap*

Mean value for 500, 1000 and 2,000 c/s

No. of cases	Air bone gap (db)	Per cent
129	0–10	84.0
1[illegible]	11–20	10.3
[illegible]	21–30	5.7
—	31	—

Table 2 shows the actual hearing improvement in decibels as calculated from the same frequencies.

It is seen that in most of the cases the improvement was from 21–40 db (61.1%). In 13.1% the improvement exceeded 40 db. The gain was greater than obtained with fenestration of the semicircular canal.

In many cases we noticed a marked improvement in bone conduction. There may be several reasons for this change; the most plausible is that bone conduction is influenced by the removal of the fixed stapes footplate. In this connection, however, we cannot discuss this particular question in greater detail and will resume it later in another publication.

Table 3 presents the postoperative air bone gap. In the great majority of cases the gap was practically closed.

As regards the lasting results, it is not possible as yet to draw definite conclusions. The observation period is still too short. Table 4 shows the results after six and 12 months.

Of the 12 patients observed for one year, nine showed distinct impairment. This seems to be a rather large figure. However, on looking more closely at the cases the situation does not appear so bad. In five of these nine cases it was not possible to remove the whole footplate because of the thickness and large extent of the otosclerotic process; closure of the window is thus understandable. In our earlier cases we did not pay enough attention to the right length of the remaining crura. When the soft tissue in the window shrinks in these cases, the connection between the incus and the window becomes looser and consequently the hearing deteriorates. The remaining four cases belong to this group. This impairment usually occurred during the first 3–4 months. A revision operation with replacement of the crura by a new and sufficiently long tube restored the hearing to the primary levels.

All these nine cases are among the 12 cases constituting the 1 year follow-

TABLE 4. *Follow up examinations*

Observation period	Unchanged	Impaired
1 year	12	9
6 months	30	12

up group mentioned below In six of these 12 cases the cause of impairment was the too short stapes In the present material none of the cases in which the whole window was successfully opened have later shown impairment due to regrowth of otosclerotic bone in the window region In all cases in which hearing was impaired this occurred within the first six months of the operation

In recent literature the danger of inner ear lesions arising in connection with this method is very often emphasized In our cases we have not seen a single dead labyrinth and there have been only two severe late cochlear degenerations In some cases a slight impairment has occurred at the frequencies 4000 and 8000 cps without major influence on hearing speech These will be published later in another connection

DISCUSSION AND CONCLUSIONS

In our experience the following points should be stressed in oval window surgery

The operation should be performed under general anesthesia This is the only way to avoid unexpected head movements of the patient which may jeopardize the result when cleaning the window margins and working in the middle ear

The window should be made as large as possible and the stapes footplate including its margins should be removed *in toto* A small fragment of the footplate rim may fairly easily remain in the posterior part of the window especially When later the crura or a polyethylene tube are placed in position on the fascia they may come to lie on a residual fragment of the stapes plate with the result that the ossicular chain cannot move freely and the desired improvement in hearing is not obtained

When trimming the window margins a fragment of the footplate may enter the vestibule No attempt at removal should then be made The danger of injuring the membraneous labyrinth is too great The same applies to blood that may have entered the vestibule Fragments of the footplate or a small amount of blood do not impair the results

A graft taken from the fascia of the temporal muscle through an endaural incision has proved a very good covering material for the oval window It is easily obtainable and does not require any special preparation

For reconstruction of the ossicular chain it is possible to use either the patient s own stapes or a polyethylene tube If the former is used severing of the incudostapedial articulation should be avoided Repositioning of the stapes is frequently difficult and one should not be content with the result unless the stapes remains firmly in place when pressure is applied to the incus The natural position of the stapes is preferable but other positions also give a good result if only the stapes forms a firm bridge between the incus and the window If the stapes is in its natural position it is important that at least one of the crura is sufficiently long Too short a crus gives a good

primary result of the fascia graft is correspondingly thicker. The result however, is not lasting. When using a polyethylene tube its length is an important factor. If it is too short it will not form a proper bridge between the window and the incus, if it is too long a danger of irritation of the inner ear will be constantly present.

Labyrinthine complications can be avoided by extreme care and meticulous technique.

It seems to us that correctly and carefully performed fenestration of the oval window with *interposition is at the moment the best method used in* surgery for otosclerosis. It is suitable in all cases, early and late, in which hearing is impaired beyond the practical level, always provided that the function of the inner ear is satisfactory. This operation can be performed in the great majority of cases. Only when an exceptionally large and thick otosclerotic focus closes the window, may it be impossible to make a new fenestra in this region. In such cases fenestration of the semicircular canal retains its importance.

ZUSAMMENFASSUNG

115 Fälle, die von den Verfassern an der Otolaryngologischen Universitätsklinik in Turku operiert wurden, werden beschrieben. Am wichtigsten bei der Operation waren folgende Punkte: Intubationsnarkose, Endauralinzision, Tympanotomie, Frakturierung der Crura des Steigbügels und totale Entfernung der Fussplatte, Verschluss des Fensters mit einem Transplantat von Schläfenmuskelfaszie, Reposition der Schenkel oder Ersatz des Stapes durch ein Polyäthylenröhrchen und Zurückklappen der Trommelfellmembran und der Haut des Gehörganges an ihren Platz.

Die Resultate zeigten, dass der Luft-Knochenspalt sich in 81% aller Fälle schloss. *In 10.3% behielt der Spalt eine Breite von 11 bis 20 db und in 0.7% von 21 bis* 30 db. In 12 Fällen (8.2%) ging die Hörfähigkeit auf die präoperative Stufe zurück. Dieser Verlust trat ohne Ausnahme innerhalb der ersten 6 Monate nach der Operation auf. Sie wurde verursacht, entweder durch zu kurze Crura, die keine feste Brücke mehr zwischen dem Incus und dem Fenster bildeten, wenn das Faszietransplantat sich zusammenzog, oder durch Wiederverknöcherung des Fensters in solchen Fällen, wo dieses von Anfang an wegen der Grösse des otosklerotischen Herdes nicht vollständig eröffnet werden konnte. Keine Wiederverknöcherung des Fensters sah man dagegen in solchen Fällen, bei denen eine völlige Eröffnung möglich war. Komplikationen in Form von Taubheit traten nicht ein. 2 Fälle von späterer Degeneration kamen vor.

Die Autoren sind der Ansicht, dass Fenestration des ovalen Fensters mit Interposition der Crura oder eines Polyäthylenröhrchens die beste der gegenwärtigen Operationsmethoden gegen Otosklerose sind. Deckung des Fensters mit einem Transplantat von Schläfenmuskelfaszie ist eine einfache und sehr befriedigende Methode.

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The Otolaryngological Univ Clinic
Turku Finland

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PREOPERATIVE MEASURES FOR TRACHEOTOMY IN SEVERE PSEUDOCROUP

H. Diamant and G. Marcusson
Stockholm, Sweden

From the Ear, Nose and Throat Department (Head: Prof. C. A. Hamberger), Karolinska Sjukhuset, Stockholm 60

During the one-year period from September 1960 through August 1961 a substantial rise in the incidence of severe pseudocroup was observed. Tracheotomy was required in 17 of the cases in this series. In our experience considerable value attaches to immediate administration of oxygen and air under positive pressure to assist the respiration and thus reduce the anoxia. Attention is drawn to the advisability of using intubation anesthesia for tracheotomy, with the aim of preoperatively raising the negative intrathoracic pressure, thereby lessening the danger of mediastinal emphysema and pneumothorax.

As regards pulmonary ventilation and initial anesthesia in epiglottitis emphasis is placed on the importance of measures designed to widen the entrance to the larynx and to prevent a backward and downward displacement of the epiglottis.

In cases with supraglottic edema a slender, relatively firm tube is technically the simplest and best suited for intubation.

In subglottic edema, on the other hand, it is advisable to employ the largest tube that will pass the glottis. By careful manipulation the tube can be guided past the subglottic edema, which presents little resistance. Such a tube will then facilitate the removal of mucus and crusts from the trachea, a procedure that is difficult or impossible when slender tubes are employed.

Between September 1960 and August 1961 the number of pseudocroup cases admitted to the Otolaryngology Department of Karolinska Sjukhuset rose substantially. Quite apart from the increased incidence, it is significant that among these children were a number with very serious and therapeutically difficult conditions. During this one-year period 17 tracheotomies were performed, as compared with a total of 55 in a previously reported ten-year pseudocroup series dating from 1949 through 1958 (Bergstrom & Diamant 1960).

A rising incidence of acute laryngitis during recent years has also been noted by other authors (Leegard 1960, Kossowska 1961). No tenable explanation of the increase can be found.

In the above-mentioned 17 tracheotomized children the indication for tracheotomy was acute severe anoxia. A number of interesting circumstances came to light during the initial treatment of the severe, acute subglottic edema

Thus it seems to us worth while to discuss certain therapeutic details as well as the technique employed for anesthesia and tracheotomy of children with acute laryngitis. Following are brief reports of three illustrative cases: one with subglottic edema, a second with supraglottic edema, and a third with epiglottitis complicated by rarely seen purulent tracheobronchitis.

The first of these patients was a 2½ year old, previously healthy girl. After increasing respiratory distress for two hours, she was admitted in poor condition, with severe dyspnea. She was given deltacortril intramuscularly as well as chloromycetin and phenergan. After 30 minutes her condition was however appreciably worse and it was necessary to resort to tracheotomy. Intubation with a slender tube involved such difficulties that it was essential to proceed with the tracheotomy before fully satisfactory ventilation and anesthesia had been secured. As soon as the trachea had been opened it was possible to aspirate copious amounts of secretion from the trachea and bronchi. Post-tracheotomy roentgenograms disclosed fairly extensive mediastinal emphysema, which, however, did not complicate the postoperative course. The cannula was removed on the fourth day and the child was discharged as fit.

The second case was a 2 year old boy who, on admission, had been suffering from respiratory distress for about an hour. Pharyngoscopic inspection revealed supraglottic edema and a severely inflamed, hazelnut-sized swelling of the epiglottis. Immediate tracheotomy was decided upon. The child in the sitting position was ventilated with oxygen. Gaseous anesthesia was given and intubation performed with a fairly slender tube, the child still in sitting position. The tracheotomy presented no difficulties. No complications arose during the postoperative course.

The third case was that of a boy just over 2½ years old who had been afflicted with an upper respiratory infection for the past 14 days. He was admitted in poor condition and with inspiratory stridor of two hours' duration. Pharyngoscopic inspection showed epiglottitis, and it was decided to tracheotomize the patient without delay. He was anesthetized with vinydan concurrently with administration of oxygen under positive pressure. The use of a slender no. 1 tube for intubation was not as effective as had been expected: only a small volume of secretion could be aspirated.

It was necessary to speed up the tracheotomy when the patient's condition abruptly deteriorated following an upward shift of the tube. In the trachea there was a quantity of blood-tinged mucus. On removal of the latter and introduction of a no. 3 silver cannula, the condition immediately improved. Apart from moderate mediastinal emphysema the postoperative course was quite uneventful.

DISCUSSION

The three cases outlined above typify, in principle, not only the 17 tracheotomized cases in this series but pseudocroup cases in general (Bergstrom & Diamant 1960). The children were subjected to tracheotomy

immediately or shortly after admission. It seems unlikely that the current therapeutic approach entailing administration of cortisone drugs will lead to an appreciable decrease in the incidence of tracheotomy (Mårtensson *et al.* 1960). It had been hoped that such a reduction might be possible (Mårtensson & Nilsson 1958).

In none of our 17 cases did cortisone therapy obviate the need for tracheotomy. The drug, however, was administered intramuscularly, and it is possible that if injected intravenously, cortisone would prove more effective.

In view of considerations discussed in a previous paper (Bergström & Diamant 1960), tracheotomy was invariably preceded by intubation, the aim being to equalize, as far as possible, the negative intrathoracic pressure and thus to lessen the danger of mediastinal emphysema.

It is important in pseudocroup cases, both subglottic and supraglottic, to combat the anoxia as soon as possible. Oxygen administration under positive pressure is suitable for this purpose. The object is to force oxygen and air past the respiratory obstruction when the patient inspires. In the event of demonstrable or suspected epiglottitis the child must be prevented from lying supine or with its head back. In these postures the passage of air into the larynx is impeded due to a further narrowing of the introitus laryngis by backward displacement of the severely swollen and edematous epiglottis.

Though the obstruction of the larynx in subglottic edema as a rule is less, tracheo-bronchitic lesions frequently jeopardize the airway lumen. It is extremely important, particularly in desperate cases, to assist the respiration by use of, for instance, an anesthesia machine, a Ruben bag, or the mouth-to-mouth method (Benveniste *et al.* 1960).

These remarks concerning assisted respiration are, of course, equally valid for the initial stage of gaseous anesthesia. Patients with supraglottic edema should be sitting upright, preferably leaning somewhat forward with the lower jaw held forward, so that the epiglottis is shifted upward and the entrance to the larynx widened.

In cases with epiglottitis even the experienced laryngologist or anesthesiologist may, by virtue of the completely altered anatomy, find it difficult to insert the tube. Here it is advisable to use slender but relatively firm tubes. These can often be manipulated, though not readily, into position, whereas tubes of larger caliber cannot be forced through resistant parts of the lumen and tend, moreover, to increase the hazard of traumatization. Despite the fine caliber of the tube, both ventilation and anesthesia are usually satisfactory, since in this condition the laryngitis does not involve the subglottic region and there is little danger of the tube's becoming occluded by crusts and mucus. An illustrative case is no. 2 above.

In case 3 with supraglottic pseudocroup we encountered an unusual complication of a type which is most likely to arise in cases with relatively long histories. When in such cases the introduction of a sufficiently large tube proves difficult, it is advisable to induce light anesthesia under positive pressure with supplementary local anesthesia, and to perform emergency

tracheotomy, while foregoing measures to raise the negative intrathoracic pressure.

Entirely different circumstances are present in subglottic edema. While the position of the head and body is of no great significance at induction and maintenance of anesthesia, the edema and the frequently profuse secretion give rise to major problems.

When intubating children with subglottic edema one is tempted to employ a slender tube, since one may hesitate to force a larger tube past the frequently slit-like aperture discernible between the subglottic edematous swellings which bulge into the lumen principally from the lateral walls. It is important to bear in mind, however, that this edema presents little resistance and can be passed by any tube that will pass the glottis. This consideration is so much the more important in that the trachea often contains large quantities of fairly thick mucus which can occlude a narrow tube lumen. Effective suction is not possible with small tubes, and the pulmonary ventilation is jeopardized. Case 1 demonstrates how readily difficulties may occur.

ZUSAMMENFASSUNG

Im Zeitraum von einem Jahr zwischen September 1960 bis Ende August 1961 wurde eine beträchtliche Zunahme der Fälle von schwerem Pseudokrupp beobachtet. Tracheotomie musste bei 17 Fällen dieser Untersuchungsserie durchgeführt werden.

Nach unserer Erfahrung ist es besonders wichtig, dass sofort Sauerstoff und Luft unter Überdruck gegeben werden, um die Atmung zu unterstützen und die Anoxie zu vermindern. Für die Tracheotomie wird Intubationsnarkose empfohlen, um vor der Operation den negativen intrathorakalen Druck zu steigern, wodurch die Gefahr von mediastinalem Emphysem und Pneumothorax herabgemindert wird.

Für die Ventilation der Lungen und die einleitende Anästhesie bei Epiglottitis wird die Bedeutung von Massnahmen unterstrichen, die den Zugang zum Larynx erweitern und eine Verschiebung der Epiglottis nach hinten und unten verhindern.

In Fällen von Ödem in der Region oberhalb der Epiglottis wird die Intubation technisch am leichtesten und einfachsten mit einem schmalen, aber verhältnismässig steifen Gummiröhrchen durchgeführt.

Bei Subglottisödem dagegen wird empfohlen, eine Kanüle mit dem gröbsten Kaliber, das durch die Glottis passieren kann, zu verwenden. Durch vorsichtige Manipulation kann das Rohr an dem Subglottisödem vorbeigeführt werden, welches wenig Widerstand leistet. Eine solche Kanüle wird dann das Entfernen von Schleim und Krusten aus der Trachea erleichtern, eine Massnahme, die bei Verwendung von einem schmalen Röhrchen schwierig oder undurchführbar ist.

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The E N T Dept, Karolinska Sjukhuset, Stockholm 60

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TREATMENT OF MENIERE'S DISEASE WITH HYDROCHLOROTHIAZIDE

INGEMAR NORELL and JAN STAHLE
Uppsala, Sweden

From the Department of Otolaryngology (Head: Prof. A. Sjöberg, M.D.), University Hospital, Uppsala

Hydrochlorothiazide, which is a diuretic, can be thought to reduce the intra-labyrinthine pressure. Fifty-seven cases with Menière's disease of varying duration have been treated. The classical triad of symptoms together with recruitment in the Békésy audiogram were present in every case. The treatment was given as a course of two to three weeks, which was repeated following further attacks. The average observation time was six months.

The hearing results show a clear relation to the length of disease. In 31 cases with length of disease less than two years, hearing improvement was noted in 57%, while in 26 cases with length of disease more than two years hearing improvement was only obtained in 27%. In 75% of cases diminution of or freedom from giddiness was noted.

Treatment can cut short attacks of vertigo if it is begun during the prevertiginous aura. In no case did hearing loss increase during the observation time, which we think shows that the sensory epithelium in the inner ear is preserved from further damage. We consider this to be the most important observation in this investigation and it indicates that hydrochlorothiazide has a beneficial effect in Menière's disease.

INTRODUCTION

The medical treatment of Menière's disease must still be considered empirical. In spite of considerable research the cause and pathology of the disease have not yet been satisfactorily elucidated. It is almost certainly localized to the inner ear. In favour of this are the good results of a large number of operated patients (Olivecrona 1943, Cawthorne & Hewlett 1954, Arslan 1953, etc.).

A generally comprehensive theory, first developed more than 30 years ago by Brunner, Dederding and Mygind, is that there is a periodic accumulation of fluid and/or salt in the inner ear as a result of disturbed vasomotor function. Experimentally, vasospasm in the arteries to the inner ear has been observed (Seymour 1960) and this is thought to lead secondarily to endolymphatic hydrops (Golding-Wood 1960).

Cawthorne & Hewlett have assumed that in the active phase there is a disturbance of the normal balance between the production and disposal of the endolymph, which leads to a rise in endolymphatic pressure. At any time during this period there may be a critical increase in the endolymphatic

pressure, which if sufficient to squeeze the blood out of the capillaries, will result in an attack.

An alteration in the chemical constitution of the endolymph has been assumed by several (Schick 1943, Lindsay 1946). However, chemical analysis of the endolymph from severe cases of Menière's disease which have been treated by destructive surgery, is in favour of a normal composition of the endolymph in this phase of the disease (Rauch 1960, Wullstein & Rauch 1961).

Many have attributed the disease to allergy (Dohlman 1933, Atkinson 1941, Horton 1941, Williams 1952), which may give a spasm of the internal auditory artery or its branches. This would secondarily lead to a transudation of endolymph of altered nature and higher osmotic pressure. A dialysis of fluid through Reissner's membrane would follow producing distension of the endolymphatic system.

Common to the majority of theories is the retention of fluid and/or salts in the membranous labyrinth. This phenomenon is to some extent supported by Hallpike & Cairns' histological findings in two cases of dilatation in the labyrinth and cochlea. However, the histological basis for the hydrops theory is still very slight. Up to now a total of only 24 cases have been examined, of which several revealed no dilatation (Berggren 1949, Wustrow & Berkowsky 1960). The latest report concerns the inner ears from Dida Dederding, who suffered from severe Menière's disease. Following postmortem, Kristensen (1961) reports: "... beyond an enormous dilatation of the endolymphatic system as well in the cochlea as in the vestibulum, pronounced degeneration of the organ of Corti plus the first neuron is found, whereas no definite degeneration changes can be traced in the ampullary crests, in the maculae or in the vestibular ganglion. Thus there is a very good coincidence between the histopathology of the peripheral acoustic organ and the acoustic symptoms, whereas there is a striking discrepancy between the histologically apparently normal vestibular sense organs and the formerly severe vestibular symptoms accompanied by loss of caloric reaction."

If a hydrops of the inner ear is acceptable, treatment with diuretics is logical. As early as 1931 Dederding gave Salyrgan® with good effect, but stopped because of its toxicity. Since then, diuretics have only been used to a limited extent in the treatment of Menière's disease (Schick 1943, Varga 1958). The appearance of effective, pleasant, oral preparations has been a stimulus for trying this method of treatment again. Preliminary results have previously been published (Ståhle 1959, Norell & Ståhle 1961). Similar treatment has also been used in sudden deafness (Ståhle & Öberg 1960).

Method of Treatment

Hydrochlorothiazide[1], which is a diuretic of sulphonamide type, was used. Its pharmacological effect is an inhibition of chloride and sodium reabsorp-

[1] Esidrex®, a product of CIBA, was used in this investigation.

tion in the renal tubules. This produces an increased diuresis, which begins after about 2 hours and is at its maximum 4–6 hours after oral administration. Excretion of potassium also increases, but to a lesser extent. With prolonged treatment potassium must be added.

Our dosage has been 25 mg three times daily during the first 3–4 days, followed by 10–25 mg twice daily during the following 2–3 weeks. In cases of repeated courses of treatment potassium chloride 1 g two times daily has been added. No special diet or other medical treatment has been given at the same time as the hydrochlorothiazide.

In all cases hydrochlorothiazide was introduced at the same time as the attack of vertigo or during the weeks immediately following. Repeated courses of treatment were given in cases with relapsing attacks of giddiness.

Material and Methods of Investigation

Fifty-seven patients, 35 women and 22 men, were treated. The average age was 30 years, which completely agrees with the figure of Russell Brain (1958). More than half of the patients lay in hospital. The series is presented in two groups, of about the same size, based on the duration of the disease before treatment (Table 1). In Group I the duration of disease was less than 2 years and in Group II two years and more.

Before treatment was begun, otoneurological examination including nystagmography were carried out as previously suggested (Stahle 1958). The tone audiogram was assessed at frequencies of 250, 500, 1000 and 2000 cps. The results are shown in Tables 1 and 2 with average values. In seven cases where the disease was considered to be bilateral the assessment was based on the ear which had less hearing. In all cases the Békésy audiogram showed

TABLE 1. *Hearing loss before treatment*

Duration of disease	<30 db	>30 db	Total
Group I years	12	19	31
Group II years	5	21	26
		Total	57

TABLE 2. *Hearing at follow-up*

Duration of disease	Improvement 10 db	Improvement 30 db	Unchanged (10 db)	Loss (10 db)	Total
Group I years	18	6	13	[illegible]	31
Group II years		3	13	0	26
				Total	57

TABLE 3. *Vestibular function before and after treatment*

Duration of disease	No. of patients	Vestibular function before treatment		No. normal after treatment (no. investigated)	Improvement of dizziness
Group I <[illegible] years	31	Normal	14	5 (14)	23
		Pathological	17		
Group II >[illegible] years	26	Normal	6	6 (14)	20
		Pathological	20		
Total	57				43

recruitment. During and after the treatment the patient has been followed with repeated hearing and vestibular tests.

The time of observation has been 1–18 months with an average of six months. The results are based on a comparison between the first and last examinations. Labyrinthine function has not been tested in all cases at the end of the observation time.

Results

The results are assembled in two tables where Table 2 is based on hearing and *Table 3 on labyrinthine function. The best results were obtained in* Group I (more recent cases) in which hearing improvement of >10 db was obtained in 18 out of 31 cases (58 %). In Group II consisting of more advanced cases, hearing improvement was found in only seven cases out of 26 (27 %). A hearing improvement of 30 db and more is rare, occurring in Group I in six cases and in Group II in three cases.

In the tables a hearing variation of ± 10 db has been considered as unchanged hearing and was found in 13 and 19 cases respectively. A mean deterioration of >10 db from the initial audiogram was not recorded in a single case at follow up.

Before treatment vestibular function was pathological in a total of 37 cases. The number of pathological cases is greatest in Group II. Follow up was carried out in 28 cases and a return to normal was found in 11 cases. Considerable improvement or complete freedom from vertigo was reported in 43 cases (75 %), to a large extent equally distributed in both groups.

During the period of observation repeated attacks of vertigo have occurred in nine cases in Group I and 14 cases in Group II. If possible a further course of treatment with hydrochlorothiazide was given. By beginning treatment rapidly it was possible in several cases to cut short an attack.

FIG. 1. Pure tone audiogram of the right ear before and after 10 days' treatment with hydrochlorothiazide. Left ear normal.

FIG. 2. Békésy audiogram from the same patient as in Fig. 1. Before treatment recruitment (upper curve), after treatment normal pattern (lower curve).

Fig. 1

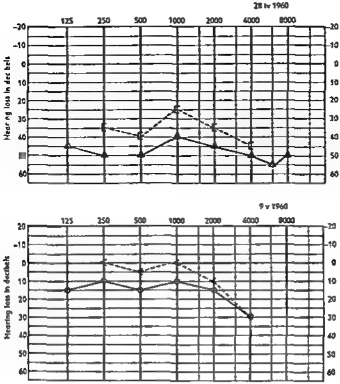
28 iv 1960
125 250 500 1000 2000 4000 8000
Hearing loss in decibels
9 v 1960
125 250 500 1000 2000 4000 8000
Hearing loss in decibels

Fig. 2

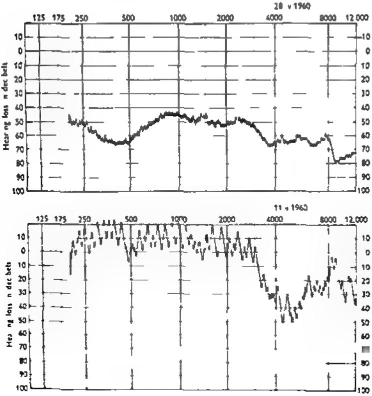
28 v 1960
125 175 250 500 1000 2000 4000 8000 12 000
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FIG. 1. Pure t[illegible] [illegible]gram of the right ear before and after 10 days' treatment with hydrochlorothiazide [illegible] [illegible]rmal.

FIG. 2. Békésy a[illegible] from the same patient as in Fig. 1. Before treatment recruitment (upper curve), after tr[illegible] normal pattern (lower curve).

implies that the length of time of the illness is here of minor importance. The psychological factor of repeated visits to the doctor with advice on a suitable mode of life must certainly play an important part.

A comparison between our results and those described following other methods of treatment are of importance in assessing the value of the diuretic treatment. Cawthorne states that 50 % are cured and a further 25 % are improved independently of which conservative treatment is used. Simson Hall has noted freedom from vertigo in about 80 % after treatment with salt free diet, histamine and nicotinic acid. Wustrow & Borkowsky obtained a clear improvement in 66 % after a regime consisting of rest in bed, Diamox®, sedatives, vasodilator drugs and vitamins. There have been earlier reports from Sweden of improvement of vertigo in about 70 % after varying conservative treatment (Nylen, 1949; Lystam & Walander 1952; Preber 1953). As far as the symptom of vertigo is concerned the results seem to agree with ours, so that the choice of treatment may seem to be irrelevant. However, an accurate description of the effects of different treatments on cochlear function is missing from the series mentioned above, so that a complete comparison is impossible.

An observation was made which can be of essential importance. Repeated hearing tests have shown that in none of the 57 cases has hearing deteriorated compared with the original value during the time of observation. We describe deterioration as an average fall in the audiogram of > 10 db in the frequencies 250, 500, 1000 and 2000 cps. Our explanation of this is that the treatment removed fluid from the inner ear so rapidly that further degeneration of the sensory epithelium was prevented. *Thus hydrochlorothiazide may protect the inner ear from irreversible lesions.* We consider this result of greater value than a description of the number of cases improved.

The results of the caloric tests agree to a certain extent with those of the hearing tests. A clear canal paresis was only found in four cases out of a total of 28 examined at follow up. In comparison may be mentioned that Cawthorne & Hewlett found canal paresis in more than 70 %.

There were repeated attacks of vertigo during the time of observation in 23 patients (40 %), usually isolated but in a few cases repeated. When these attacks occurred a new course of treatment has been given with hydrochlorothiazide where possible. In this way it has been found that an attack of giddiness can more or less be cut short if the drug is taken as soon as possible after the beginning of the attack. The best effect was obtained in patients who had an aura before the attack of vertigo. In this case hydrochlorothiazide could be administered before the actual vertigo attack or at an early stage of the attack, so that the intensity could be diminished and in some cases even completely prevented. Every attack should be thought of as an injury to the sensory epithelium which as a result becomes damaged. Abolition or diminution of an attack is therefore a good therapeutic effect.

An interesting phenomenon appears on comparison of the hearing and the vestibular function, in which the results are not parallel. At the first examina-

tion all patients showed a nerve deafness and recruitment while the labyrinthine function was normal in 20 and pathological in 37 (Table 3). The majority of normal patients (14) are among the early cases (Group I). The question is whether the hydrops of the endolymph affects the cochlea earlier and more than the semicircular canals and whether the lesion in the semicircular canals is more easily reversible than that in the cochlea. It should be remembered that physiologically the labyrinth is an older organ than the cochlea and according to Semon Rosenbach's law (Ask Upmark 1951) should be the less vulnerable of the two. Another more likely explanation is that our methods of investigation, especially the caloric test, are too coarse to be able to record a vestibular lesion. That there is such a lesion is not in doubt, as shown by the attack of vertigo and the accompanying nystagmus (Aschan & Stahle 1957). Kristensen's findings (1961) of severe histological changes in the cochlea and vestibule but not in the ampullar organ are in good agreement with our clinical observations.

The vestibular tests show results differing from several large series in the literature (Cawthorne *et al.* 1942, Preber 1953, Cawthorne & Hewlett 1954). In our series there is a relatively large number of "normal" patients (37 %) and patients with spontaneous and positional nystagmus (60 %). On the other hand the caloric test was only pathological in about 40 %. In the series referred to above there was no spontaneous or positional nystagmus, but on the other hand the caloric test was considered as pathological in up to 90 % (Cawthorne & Hewlett). However, these clear discrepancies have simple explanations. Our series has been mostly examined for the first time during or soon after an attack, which explains the high incidence of spontaneous or positional nystagmus. More than half of the series have a total illness time of less than two years. On the other hand the English series seems to have been tested in dizziness-free intervals and to consist of advanced cases where many were considered suitable for operation and thus represented the irreversible phase of the illness. These facts must be clear to those who later want to test diuretics or other drugs and compare their own series and results with others.

Hydrochlorothiazide treatment is contraindicated in uraemia. Side effects are rare. It is important to know that prolonged treatment can produce *hypokalaemic hypochloraemic alkalosis*. Such conditions are described in patients with cardiac failure (Weinfeld 1961). For this reason we have given 2 g potassium chloride daily in those cases in which the treatment time has exceeded two weeks. Fruit juice is rich in potassium and another suitable substitute we recommend our patients. Two patients developed temporary nausea, diarrhoea and abdominal pain, which they referred to the treatment. *There have not been any serious side effects.*

ZUSAMMENFASSUNG

Hydrochlorothiazide, ein Diureticum, dürfte vermutlich den intralabyrinthischen Druck senken. Es wurden siebenundfünfzig Fälle von Menière's Krankheit

verschiedener Dauer behandelt Die klassische Symptomentriade mit Recruitment in der Békésy Audiogramme lagen in sämtlichen Fällen vor Der Behandlungskurs dauerte [illegible] Wochen und wurde nachfolgend weiterer Anfälle wiederholt

Die Hörergebnisse weisen auf ein deutliches Verhältnis zur Krankheitsdauer hin In 31 Fällen <zweijähriger Dauer konnte eine Verbesserung des Hörvermögens in 51 v H festgestellt werden, wogegen in 26 Fällen >zweijähriger Dauer wurde Hörverbesserung nur in 27 v H der Fälle erreicht In 75 v H der Fälle wurde Ermässigung der Schwindels oder Befreiung von demselben beobachtet

Die Behandlung kann Schwindelanfälle plötzlich abbrechen, falls sie in der praevertiginösen Aura eingesetzt wird In keinem einzigen Falle ist der Hörverlust während der Observationszeit angestiegen welches unserer Meinung nach davon zeugen dürfte, dass das sensorische Epithelium des Innerohrs von weiteren Schaden geschützt war Wir sind der Ansicht, dass dieses die bei weitem wichtigste Beobachtung der Untersuchung ist und darauf hinweist, dass das Hydrochlorothiazide einen wohltätigen Einfluss auf Menieres Krankheit ausübt

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University Hospital, Uppsala, Sweden

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OTOLOGICAL OBSERVATIONS ON THE "TREACHER COLLINS SYNDROME"

G. Herberts
Umeå, Sweden

From the Department of Ololaryngology (Head: Prof. G. Herberts), Royal Medical School, Umeå

The "Treacher Collins syndrome", of which the most common symptoms are deformities of the eyelids, ears and upper and lower jaws, is described. The etiology of the syndrome is discussed and a short review of previous medical opinion is given. Three cases are described, in order to illustrate the need for otological examination in cases in which an operation for improvement of hearing is possible. As the etiology is still unclear, a study of the causal factors, especially in embryonic development, is desirable.

The synonyms of this syndrome are Franceschetti's syndrome, bilateral mandibulo-facial agenesi, dysostosis mandibulo-facialis, dysplasia foetalis, dysgenesis faciei, and Streeter's faciale dysplasie. The syndrome was described by the English ophthalmologist, Treacher Collins, in 1900, but, as early as 1888, Berry reported on a case of a 15 year old girl with lateral coloboma in both lower eyelids and obliquely set eyes of anti-mongoloid type (i.e. the line of the upper lid directed laterally downwards). In 1943 Ida Mann & Kilner each reported a case. Mann suggested that the cause lay in a retardation of differentiation of the maxillary mesoderm. In 1949 Straith & Lewis described a family of five, mother and four children, all of them showing signs of the syndrome. In 1950 Harrison published findings in 2 cases and in 1956 Snyder reported on 7 patients.

Symptoms

Among the most common symptoms are deformities which affect the eyelids, the ears, and the upper and lower jaws.

The eyelids. As has already been said, the line of the lids is oblique laterally and caudally—the opposite to what is observed in mongoloids. A "notch", which can be large or small, in the lower lid at the transition between the medial two thirds and the lateral third. Lashes on the medial two thirds are either absent or poorly developed. The meibomian glands and the punctum lacrimalis may be absent. Both sight and the functioning of the extra ocular musculature are normal.

The ears. Symptoms can vary from slight deformity to total absence of the outer ear. The external meatus is often lacking. Slight to pronounced deaf

Fig 1

Fig 2

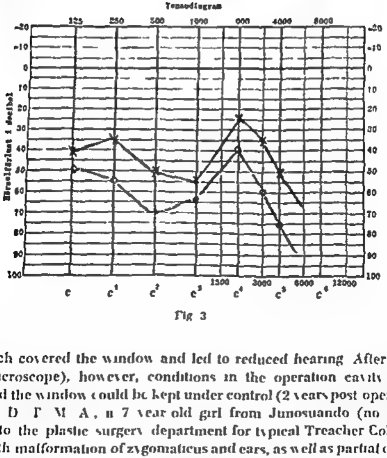

Fig 3

crust which covered the window and led to reduced hearing After cleaning (using microscope), however, conditions in the operation cavity and the area round the window could be kept under control (2 years post operatively)

Case 2 D F M A, a 7 year old girl from Junosuando (no 332/58) Referred to the plastic surgery department for typical Treacher Collins syndrome with malformation of zygomaticus and ears, as *well* as partial deafness Siblings and parents had normal appearance, no case of hare lip or cleft palate *in the family Patient's* deformity was congenital *She* was *reserved* and had not gone to school, but, according to the mother, her development was normal Her appearance can be seen in the pictures here reproduced *(Figs 4 5)*

Fig 4

Fig 5

Fig 6

Ear examination showed pronounced deformities of the outer ears with absence of external meatus Marked conductive deafness (60–70 dB) with normal bone conduction X ray examination showed defective zygomaticus bilaterally and pronounced underdevelopment of the lower jaw (Fig 6) The upper jaw was also underdeveloped The cell systems were in an arrested state through pneumatisation marked sclerosis without destructive processes The pori acustici interni were of normal width the semicircular canals and cochlea being visible on both sides on the other hand there were no conclusive signs of the ossicles

Fig. 7

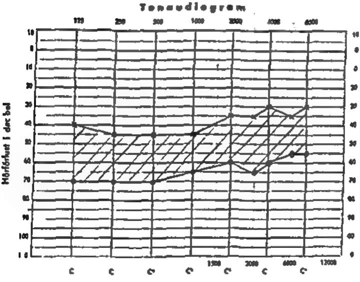

Fig. 8

It was difficult to communicate with the patient. She had on some few occasions said "mamma" and a few isolated Finnish words. Before plastic correction of the outer ear deformities was attempted an exploration of the middle ear seemed indicated to see whether a hearing improvement operation could not also be carried out. Upon exploration there was noticed a pathological bone in the processus mastoideus of osteoid character with scattered islets of cartilage (Fig. 7).

Eventually it proved possible to make an opening into the cavity corresponding to the aditus and antrum. A nucleus of bone covered the middle

Fig 9

Fig 10

Fig 11

ear which when removed revealed a covering of the same bony matter corresponding to the anterior part of a thick tympanic membrane The shaft of the malleus was missing but its malformed head and the incus likewise malformed remained The facialis was free of bony covering in the middle ear A mobile stapes was present and the recess of the window was normal The operation was carried out as a cavum minor plastic —meaning that the lower portion of the middle ear was closed off from the recess of the oval

window. A skin graft was placed in the cavity to try to obtain a passage for sound to the middle ear. Epithelialisation of the cavity was achieved *post operatively*. The patient's hearing improved by between 25 and 30 dB, as is shown from the audiogram (Fig. 8). The patient became more approachable and talked among her playmates and with the nurses.

Case 3. K. Z. G., a 2 year old girl (no. 467/60) with pronounced micrognathia and microthalbia. There were only small irregular remains of the *outer ears. The external meatus was lacking on both sides. Hearing* was very weak, but from the examinations that could be made, it was clear that some remained, especially in the lower frequencies. There was a small pocket in the right ear, possibly the remains of the branchial cleft—a not uncommon finding in this connection. Besides this, she also had a somewhat underdeveloped zygomatic region, above all the zygomaticus, and an abnormally high palatal arch (Figs. 9–11).

Dentition was normal. The patient could only open her jaws by about 2 cm; this agreed with the X-ray findings, which were as follows. The whole lower jaw was underdeveloped, more so on the left side. Joint processes were small and malformed and were moreover situated in front of the tuberculum articulare on both sides— both with open and closed mouth. X-ray of temporal bone: normal bony labyrinth and ossicles on both sides. External meatus lacking on both sides (Fig. 11). There were no marked anomalies about the eyes and both metatarsals and metacarpals appeared normal.

Both parents were healthy. At the birth of the child, the father was 51 and the mother 38. During the 2nd and 3rd month of pregnancy the mother went down with "Asiatic" flu and was feverish for a week. Otherwise she was healthy and no rubeola or other infection in the environment was found. Delivery was 2 weeks premature and went normally.

In general the child seemed normally developed, walked well and, according to the mother, could say "mamma".

Because of the child's age and the consequently increased liability to infection, she was *returned home with a view to conducting*, at a later stage, a further examination into the possibilities of operative therapy.

The first two cases, which showed such striking similarities in the facial deformities, were, however, from other points of view dissimilar. Thus the first case had fairly normal outer ears and external meati, but marked malformation of the middle and inner ears. *On the other hand*, the second case had pronounced malformation of the outer ears, lack of external meatus, malformed middle ear but with normal anatomical conditions from the stapes inwards to the labyrinth. In the first case the overwhelming proportion of deformation lay with the labyrinth area, while in the second it seems to have centred round the organs arising from the first brachial arch. Since the foundations of the *labyrinth are laid and developed earlier* (1st–2nd embryonic month) than those of the external ear and meatus (3rd embryonic month), it seems probable that the causal mechanism of the deformation

arose at an earlier stage of embryonic development (and lasted a relatively short while) in case 1 than in case 2. Even the facial deformities were more severe in case 2.

It was also interesting to find that a brother of case 1 also showed signs of similar deformity, though in this case extending to deformities of the outer ear as well; case 2 showed no such connection. According to Wrete, dysostosis mandibulo-facialis is to be considered as an irregular genetic dominant.

As regards the relevant etiology of these deformations, certain virus affections during the early stages of pregnancy have been discussed by others. It is possible that the moment of the maximal toxic effect is the decisive factor as to which part of the ear the malformation localises itself in. This would seem to be supported by the above-named differences in both the operated cases. In the third case the jaws, outer ears and external meatus were certainly affected, while, to judge from X-ray examination, the labyrinth would seem to be intact.

In summary it can be said that cases of similar malformation ought to have otological treatment in order to decide on the possibility of an operation to improve hearing function. It would naturally be worthwhile to make a study of the causal factors and their significance during different phases of embryonic development using a larger material.

ZUSAMMENFASSUNG

Falle mit solchen Missbildungen sollen unter otologische Behandlung kommen um die Moglichkeiten verbesserer Gehörfunktion beurzuteilen. Begreiflicherweise ware es sehr wertvoll die kausalen Faktoren und ihre Bedeutung der Entwicklung des Fotus während verschiedener Abschnitte in einem grosseren Material naher studieren zu können.

RÉSUMÉ

Comme résumé on peut dire que des cas avec des malformations pareilles doivent être traités otologiquement pour juger les possibilités d une audition meilleure. Il serait naturellement d une très grande valeur dans un plus grand nombre des cas de pouvoir étudier plus proche les facteurs causals et leurs importance pendant des phases differents du développement de l embryon.

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Dept. of Otolaryngology, Royal Medical School, Umeå

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NORMAL AND INSUFFICIENT TONSILS

A microscopic anatomical study

P. de Haan
Rotterdam, The Netherlands

From the Municipal Hospital and the Sophia Children's Hospital, Rotterdam

A microscopic anatomical study was made of the normal tonsillar function with special reference to the formation of reaction centres and the liberation and drainage of anti-substances. Mention is made of the significance of the normal loose tonsillar tissue for rapid and easy internal drainage of lymphocytes to the efferent lymph pathways. In the case of infection of imperfectly structured tonsillar parts, containing excessive connective tissue, dense infiltrates of lymphocytes are formed around the crypts. Local infection may result from this. Repeated serious infection in young children with still insufficient immunity, may give rise to insufficiency of the tonsils. The cavities consequently formed with necrotic contents are the cause of subsequent recurrent tonsillitis.

INTRODUCTION

The tonsils are organs in which contact is readily established between invading bacteria or viruses and lymphocytes. The invasion is via the tonsillar surface, but particularly from the crypts. Contact is made possible by a special characteristic of the epithelial cells on the adenoid tissue, viz. reticulation. This term refers to necrosis of the epithelial cells under the influence of the infection, as a result of which penetration of the agent is facilitated (Fig. 4). Lymphocytes also, however, immediately invade the small cavities of the epithelial reticulum and since these lymphocytes have an affinity for the agent, the latter is phagocytized. It can be presumed that in this manner a process is introduced which renders the bacterial production less toxic and which also enables the patients to acquire immunity to the agent. After all, it is an established fact that lymphocytes and plasma cells are of great significance in the production of antibodies (Rebuel, 1960). The object of this investigation was to improve our understanding of this *intratonsillar process by studying microscopic sections.* The tonsillar function is thus elucidated.

The tonsils are very special organs, suitable by their localization and structure to absorb a bacterial infection and cope with it by the lymphocytes. Food bacteria readily invade the palatine tonsils, while the bacteria of the respiratory tract precipitate against the rhinopharyngeal tonsil. The crypts enlarge the collecting surface area. Infection of the tonsils and its control, therefore, is within certain limits a common process for this organ.

Fig 1 Tonsil of a 3 year old child General compression resulting from Sluder operation Reaction centre formed from the superficial epithelium The adenoid tissue has not reached the surface

When the infection is too severe however it can be observed (particularly in children with still insufficient immunity) that the tonsil becames insufficient—a phenomenon associated with structural changes It is of importance to consider this in detail because the tonsil can become inferior as a result and remain so during life On the other hand the changes were studied which result from infection of imperfectly structured more fibrous tonsillar areas which offer insufficient resistance with so called focal infection as a consequence

The tonsils studied were obtained from patients who underwent tonsillectomy for recurrent tonsillitis When this operation was performed in a quiet stage we subsequently found the signs of the struggle which had taken place in the tonsil Also we saw sections particularly from children in which infection and resistance were still in full swing It was necessary to compare these specimens with those of less active tonsils which were gratefully accepted from the Utrecht histological laboratory

Tonsillar Development Structure and Normal Function

The palatine tonsils develop during the third or fourth foetal month arising from the tonsillar arch This adenoid tissue grows towards the pavement cell epithelium of the oral cavity after which its thin capsule connects itself with the subepithelial connective tissue layer However this connection is still incomplete in places in the third or fourth year of life when glandular and muscle tissue is still demonstrable between the tonsillar capsule and the pavement cell epithelium (Fig 1) Connective tissue septa extend from the

Fig. 2. Tonsil of a 16 year old female. Tonsillectomy 4 weeks after acute tonsillitis, operation under penicillin protection. Acute rheumatic changes in the joints reported in the history. Local focus of infection with cavitation.

tonsillar hilus to the surface (Fig. 2). They differ in number, thickness and course. They are sometimes closely packed and, in other cases, wide apart; in some cases they show many curves with mutual connections. They either unite with the connective tissue layer underneath the superficial epithelium or they spread in a fan shaped pattern. As will be demonstrated, the latter is an unfavourable situation. The ideal tonsil contains thin septa which diverge from the hilus.

Between the septa we find an exceedingly thin reticulum full of lymphocytes which stain a weak blue with haematoxylin (tonsillar stroma). As a result this tissue has its own special structure, characterized by looseness. Not only can epithelial offshoots invade it from the surface thus forming crypts, but microcytic lymphocytes can pass through it without difficulty; this will prove to be of paramount importance in the process of immunization. The septa thus influence the course of the crypts which, in their ideal form, have a narrow lumen so that only a small quantity of waste products can accumulate.

Under the influence of an infection in a crypt the epithelium begins to show nodular swellings, in the centre of which reticulation occurs. Soon afterwards, small blood vessels and lymphocytes are visible in the swellings (Fig. 3). As a result of the infection in the crypt, the endothelium of these blood vessels is affected, plasma enters the small focus, and the anlage of a reaction centre is thus formed. In this way the special behaviour of epithelium on adenoid tissue is shown: on the one hand its weakness against the agent manifested by reticulation, and on the other hand its tendency towards an

Fig. 3. The primordium of reaction centres from crypt epithelium.

increase in cells under the influence of the irritation. The reaction centre develops further into the stroma but, at a certain site, remains closely connected with the crypt (Fig. 4). Some single transverse section may give the impression of a reaction centre lying isolated in the stroma, but serial sections show the connection with the crypt.

Around the reaction centers, a capsule of microcytic lymphocytes is formed on the side of the crypt. The lymphocytes are supplied via the many blood vessels arising from the septa and extending around the reaction centres to the crypt epithelium (Fig. 5). They are probably also formed by mitosis from the lymphocytes of the stroma. When the reaction centre is inactive, varying numbers of cells are found in it. They are larger lymphocytes, as a rule of irregular shape, and reticulum cells. In the plasma we find a substance which stains a light pink with eosin. The centre also contains fine lymph vessels in which cells are sometimes visible. It was demonstrated by A. Fioretti (1961) that these small vessels open up into perinodular lymph vessels which lead to the larger lymph vessels of the tonsil. Drainage of the reaction centre is possible through these vessels.

During infection of the tonsil there is a considerable increase in the number

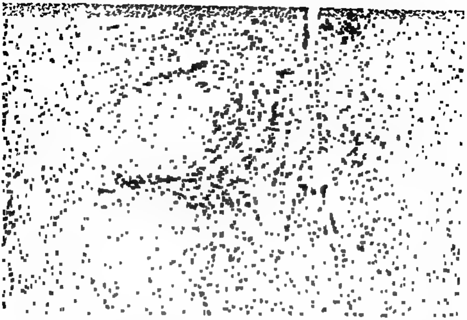

Fig. 4. Reaction centres along a narrow crypt. Inactive stage.

of microcytic lymphocytes in the so called lymphocyte capsule of the reaction centre. During the first days of the infection, the invading agent is still predominant, and toxins can still pass directly into the circulation. The patient feels ill until, soon afterwards, the agent is phagocytized to an increasing extent by the supply of lymphocytes, large numbers of which are visible

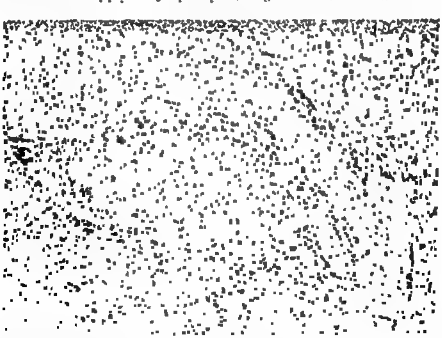

Fig. 5. Blood vessels containing abundant lymphocytes, extending from a septum and surrounding a reaction centre. Internal drainage of lymphocytes towards the septum is visible.

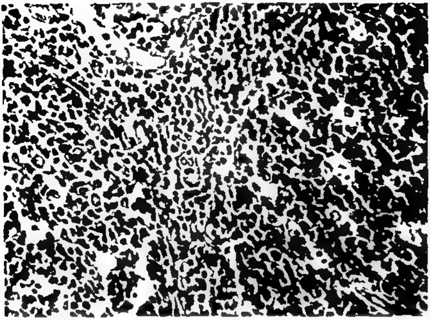

Fig. 6. Drainage of lymph from two reaction centres through lymph crevices in the stroma towards the septa.

in the afferent blood vessels (Fig. 5). These lymphocytes subsequently stain dark with haematoxylin and become very soft. When the intratonsillar pressure increases during a tonsillectomy according to Sluder, the lymphocytes are consequently seen to conflue around the reaction centre, sometimes being elongated to threads. It is remarkable that these threads point in the direction of the reaction centre (Fig. 1). The microcytic lymphocytes which have phagocytized the agent invade the reaction centre. In the liquid milieu they enlarge by swelling and stain less intensively with haematoxylin. From the lymphocyte capsule on, they are found scattered between the cells present in the reaction centre on their way to the periphery, where they close ranks (Fig. 6). An accumulation is seen particularly on the side facing the crypt. It is these cells that are greedily phagocytized by the reticulum cells. A substance is then seen to appear between them, which stains weakly red with eosin. This substance travels towards the liquid nucleus of the centre but also forces outwards and through crevices of the stroma to the lymph pathways of the septa (Fig. 6). It contains antibodies formed in the phagocytized lymphocytes. By virtue of their phagocytizing capacity, therefore, the reticulum cells play an important role in general immunization. During these periods of considerable activity many cellular mitoses are visible at sites characterized by many phagocytizing reticulum cells (Fig. 7). The two pictures are invariably found together. As the activity ceases we find a decrease in the number of large pale cells, in mitoses and in phagocytizing reticulum cells. It must be assumed that the mitoses lead to the

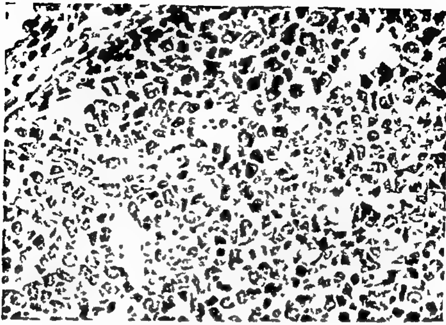

Fig. 7. Part of a reaction centre in which phag[illegible] of [illegible] lymphocytes. M[illegible]

formation of new reticulum cells, many of which were destroyed in the phagocytosis.

Of the many lymphocytes conveyed by the blood vessels towards the danger zone in the crypt wall not all can invade the reaction centres after phagocytosis of the agent; many pass by the centres towards the lymph pathways of the septa, either through epithelial channels or through tissue crevices (Fig. 5). It is possible that they subsequently invade the reaction centres of the nearby cervical lymph glands, which become swollen as a result. In the case of the tonsil we thus have internal drainage of lymphocytes and lymph, which is made possible by the loose structure of the tissue. During an infection the *tonsil distends as a result of the supply of lymphocytes and the increase in fluid in the reaction centres.* As the infection recedes, the tonsil decreases in size because lymph and lymphocytes are drained off. This internal drainage is of very great importance because it prevents stagnation in the removal of the lymphocytes which phagocytized the agent. Thus there can be a constant supply of new lymphocytes to engage in battle. Also, the tonsil rapidly diminishes in size after the infection. The phenomena described gradually decrease in intensity with increasing age, because of acquired immunity.

As to how these lymphocytes in their fight against the agent differ in behaviour from the polynuclear leucocytes engaged in battle elsewhere in the body, e.g. in a furuncle, the following can be pointed out. The latter invariably attempt to ensure outward drainage but they are of no value in immunization.

The plasma cells, with their ability to produce antibodies, are of importance to the local immunity of the crypt wall. They can be observed in many places in subepithelial localizations.

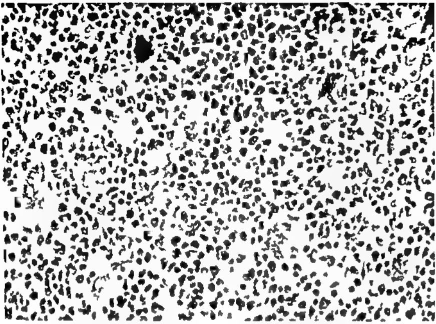

Fig. 8. Tonsil r[illegible] ove[illegible] during [illegible]ncubation perio[illegible] of measles. Part [illegible] reactio[illegible] c[illegible]ntr[illegible] with g[illegible]ant cells forming an[illegible] [illegible]ssolving

It has been previously pointed out that in infants the adenoid tissue in some places is still unconnected with the epithelium of the tonsillar surface. From these epithelial parts too reaction centres arise which therefore can apparently develop outside the existing adenoid tissue (Fig. 1).

Fig. 9. Reticulation of epithelium on fibrous adenoid tissue. Many vessels in the epithelium

It is interesting to examine tonsils which happened to be removed during the incubation period of measles. It is then found that the fight against the virus is carried out in a way which differs from that against bacteria. We find that the lymphocytes in the reaction centres hardly differ in shape and colour from the surrounding lymphocytes; they are merely localized farther apart. Under the influence of the virus giant cells are formed from these lymphocytes, which are subsequently dissolved. It is in this way that antibodies enter the plasma (Fig. 8).

Some tonsils are characterized by areas of increased fibrousness. The connective tissue septa with their areas of radiation in the adenoid tissue occupy a larger space. When a crypt has its course along such an area, reaction centres are not readily formed from its epithelial wall. The excessive connective tissue in the adenoid tissue apparently offers too great a resistance for these centres to develop (Fig. 9). Reticulation of pavement cell epithelium, however, can still occur, unless there is too much connective tissue to permit even of this. These tonsillar areas, therefore, are insufficient to cope with their function in acquiring immunity.

Various Forms of Tonsillitis

It should always be borne in mind that a tonsil readily invaded by a noxious agent should also be capable of neutralizing this agent by means of its lymphocytes. As a rule this is successfully done in the manner described, associated with transient swelling of the tonsil and, sometimes, of the regional cervical lymph glands. In the case of recurrent severe infection in young children, however, the tonsil can become insufficient; structural changes result and toxin directly enters the blood circulation (*A*). Symptoms of disease can also occur when the infection affects fibrous less functional parts of the tonsil (*B*).

A. The reaction of a tonsil to an infection is individually different. But apart from this there is a great difference between children and adults in this respect. Whereas tonsillitis is frequent in the former, it has become rare in the latter. This is explained by acquired general and local immunity of the crypt wall. In the case of recurrent severe infection in a young child, which usually involves several crypts simultaneously, various very severe symptoms can be observed. The entire epithelial wall shows extensive reticulation, even further extended due to proliferation of this epithelium. As a result, continuity is maintained as long as possible, and massive infection is prevented from invading the stroma (Fig. 10). The epithelium gradually recedes further into the stroma; an increasing quantity of reticulated epithelium with lymphocytes is cast off in the lumen of the crypt. Invading toxins affect the wall of surrounding blood vessels, and fibrinous fluid flows into the crypt. The crypt dilates more and more, until this process is arrested at the tonsillar capsule or at a septum. The fibrinous fluid then appears at the surface of the tonsil, in front of the crypt mouth. In the case of such a severe

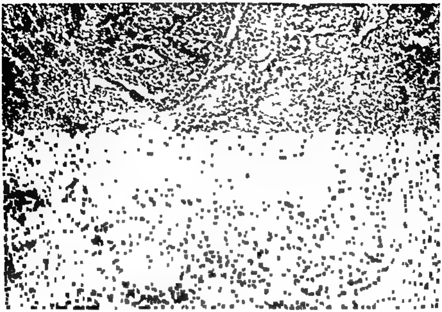

Fig 10 Acute tonsillitis in a 3 year-old child Crypt with epithelial broadening and effusion of fluid in the crypt

infection, which is beyond the normal powers of the tonsil, internal drainage has *stopped, and the tonsil attempts to rid itself of the invasion by effusion* of fluid to the crypts In such an infection, toxins of course enter the blood stream, and general illness results

Severe infection of the crypts in young children can be associated with necrosis in the greatly broadened epithelial wall In these necrotic areas which stain red with eosin, cell remnants are still visible Subsequently it is seen that the highly proliferative pavement cell epithelium which has grown in between the reaction centres, becomes completely necrotic Fragments of reticulated epithelium and tissue are consequently cast off into the crypts (Fig 11) During swallowing movements this tissue is driven to the tonsillar surface because the tonsillar part between the palatine araches is compressed by the pharyngeal muscles This compression is of great importance in cleansing the tonsil When larger tissue fragments are present however retention of the contents readily occurs and this is a serious affection of the tonsil A cyst forms in mild cases but as a rule there is an increase in the virulence of the infection The epithelium of the crypt wall then becomes necrotic in many places, and the crypt fluid invades the unprotected adenoid tissue which, because of its loose structure easily yields Much tissue becomes fragile and is cast off into the now dilated crypt It is obvious that many toxins enter the blood stream in this situation This severe affection is followed by improvement when retention is overcome by the casting off of tissue lumps, so that the process becomes inactive The resulting condition is characterized by a more or less large cavity in the tonsil, with a usually narrower efferent

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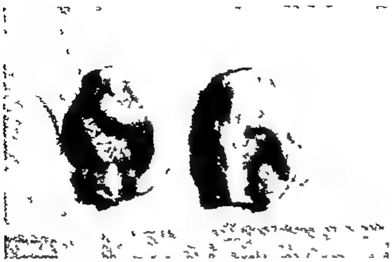

Fig 12 Tonsil with deep depression

considerable loss of tissue After several attacks recurrence is no longer possible because the crypt has disappeared to be replaced by a deep depression in the tonsil (Fig 12) When the septa are too thick and lying too close together deep channels remain in the tonsil from which necrotic tissue can be pressed They may be a constant source of infection

B It has been previously pointed out that some tonsils contain areas of increased fibrousness in which fewer reaction centres can be formed from the crypt wall These areas are inferior in the acquiring of immunity but they also afford insufficient resistance to an invading agent (Figs 9 and 13) They constitute weak spots where continuous leakage is possible For when an infection invades through a reticulated part of the epithelium it spreads in the stroma An infiltrate of microcytic lymphocytes is formed (the lymphocytes being supplied by many afferent blood vessels) There are consequently no local reaction centres which they can invade after phagocytosis of the agent The more fibrous structure of this tonsillar part also impedes the necessary smooth drainage of these lymphocytes to the lymph vessels of the septa This is in contrast with the infiltrates around the reaction centres in normal loose tonsillar regions where drainage of lymphocytes is less difficult The infiltrate becomes very dense New lymphocytes cannot be supplied without difficulty and the agent becomes predominant as a result of which toxins enter the blood stream This is also indicated by these patients symptoms viz mild pyrexia rheumatic changes The term a focal infection is used in this connection

Undergraduate X age 25 had a history of recurrent tonsillitis during the past few years (Figs 9 and 13) Improvement in the attacks of tonsillitis was followed by the occurrence of rheumatic symptoms affecting several joints Tonsillectomy was performed in an inactive stage The tonsils were small and showed normal and more fibrous parts the latter being localized chiefly

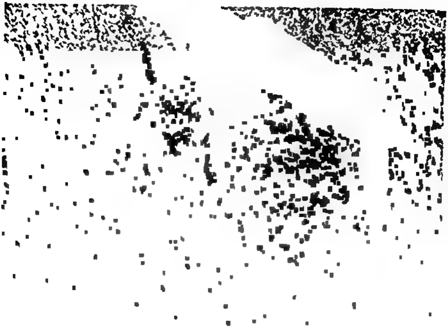

FIG. 13. Focal infection. Lymphocytic infiltrate around a crypt in a tonsillar area with much connective tissue.

between a number of crypts lying close together. In this fibrous adenoid tissue dense infiltrates of microcytic lymphocytes had formed against the infection admitted by a reticulated part of the epithelium. This infiltrate proved to afford insufficient protection. After the tonsillectomy there was no recurrence of rheumatic symptoms.

ZUSAMMENFASSUNG

Eine anatomisch-mikroskopische Untersuchung über die normale Funktion der Tonsillen mit besonderer Berücksichtigung der Bildung von Reaktionszentren und der Freisetzung und Drainage von Antikörpern wurde vorgenommen. Die Bedeutung des normalen lockeren Tonsillengewebes für schnelle und leichte innere Abfuhr von Lymphozyten zu den efferenten Lymphbahnen wird erwähnt. Bei Infektion von mangelhaft angelegte Tonsillenabschnitten mit überschüssiger Bindegewebe kommt es zu dichten Infiltraten von Lymphozyten um die Crypten herum. Dadurch kann eine fokale Infektion entstehen. Wiederholte schwere Infektion bei kleinen Kindern, ohne noch genügende Immunität, kann Anlass zu teilweiser Zerstörung der Tonsillen geben. Die Hohlräume mit nekrotischen Inhalt, die sich im Anschluss daran bilden, sind die Ursache von rezidivierenden Entzündungen der Tonsillen.

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COUNTERROLLING OF THE HUMAN EYES PRODUCED BY HEAD TILT WITH RESPECT TO GRAVITY[1]

Carl F Miller II
Pensacola, Florida, U.S A.

From the U.S Naval School of Aviation Medicine, U.S. Naval Aviation Medical Center

A photographic method of measuring torsional eye movements (counter rolling) yielded, on the average, a precision of ±5 3 minutes of arc Using this method, torsional eye movements compensatory to head (body) tilt were found in all planes tested except the sagittal In the two intermediate (±45°) planes the overall counterrolling response was quite similar and somewhat less than that found in the case of lateral tilt Counterrolling always occurred opposite to the lateral component of head tilt and increased fairly rapidly up to a maximum at a head inclination of between 60° and 90° From this point on counterrolling decreased, but at a lesser rate than it increased, reaching about zero when the head was positioned vertically downward A difference in absolute amount of torsion of the right eye found between tilting the head (body) leftward and rightward could not be established However, no difference in counterrolling could be attributed to the order (clockwise or counterclockwise) in which the measurements were made Variability in counterrolling response was found to be considerable at every position of tilt A theory attempting to explain the mechanism of otolith organ stimulation is presented

INTRODUCTION

One hundred and seventy five years ago, John Hunter (1786) published his claim that the eyes execute a conjugate rolling movement (counterrolling) around the line of sight opposite to the lateral inclination of the head Several methods have been used to measure counterrolling in man (Benjamins, 1926, Fischer, 1927, Grahe 1933, Graybiel & Woellner, 1959 de Kleyn & Versteegh, 1924, Kompanejetz, 1928, Mulder, 1897, Nagel 1896, Walton, 1948) The essential common basis of these methods is the selection of anatomical landmarks on the eye to establish a reference plane containing the line of sight which might be used in specifying the rotation of the eye around its line of sight Landmarks which have been found suitable for indicating wheel rotations include blood vessels of the eye, iris markings, and astigmatic axes detected by an ophthalmometer or, subjectively, by an astigmatism chart Wheel motions can also be measured by the rotation of

[1] The opinions or conclusions contained in this report are those of the author and do not necessarily reflect the view or endorsement of the Navy Department

the papilla around the macula (observed by a special ophthalmoscope) or by the rolling of the blind spot around the point of fixation which can be observed subjectively On the other hand certain investigators have preferred to introduce for measuring purposes artificial reference marks such as ink white gelatin fine silk sutures and egg membrane In addition the inducement of linear after images can be regarded as another artificial method of marking the eye with a reference meridian Certain of these methods are not without criticism For example the conjunctiva does not adhere firmly to the eyeball particularly in the periphery As a result the superficial blood vessels and other landmarks may not accurately reflect the torsional movement of the eyeball itself This has been given as a possible reason for failure to detect counterrolling A survey of the literature reveals a remarkable history of this phenomenon marked by alternating periods of general acceptance and denial of the existence of counterrolling

The inability to detect and measure counterrolling is readily understandable when the criteria for detecting movement do not yield precise measurement The maximum rotation reported in some cases does not exceed six degrees At present even the most accurate and sensitive methods result in about one degree of error using highly trained subjects With less sensitive methods and/or naive subjects counterrolling could be easily overlooked or unmeasurable even when the body and head positions are selected to produce maximal responses

The tilting of the head tacitly infers changing the attitude with respect to gravity of the four otolith organs within the head It is generally held that the resultant change in otolith activity reflexly affects the tonus of the extraocular muscles which is manifested by a rotation of the eyes around their lines of sight Counterrolling thus has been used as an indicator of otolith function Many clinical studies are available in the literature including those which demonstrate the lack of rolling eye movement in certain deaf mutes The counterrolling reflex can also be used in analyzing how gravity affects the activity of the graviceptors and how this contributes to the subject s awareness of the gravitational pull of the earth on his body This study is concerned primarily with the effect of gravity on the activity of graviceptors as manifested by counterrolling Other approaches to this problem include direct recording of nerve impulses in the vestibular fibers from the otolith organs Still another approach is the study of subjective awareness of what constitutes horizontal lines in the field of view perpendicular to the bisector of the primary lines of sight and what constitutes an object at eye level which lies straight ahead Reflex changes in the direction of fixation induced by otolith activity could also be investigated by recording eye movements in darkness by a sensitive photo cell (Sullivan *et al* 1958) or mechanical lever arrangement applied to the closed eye lid (Dodge 1921) or tracing the path of an after image (De Wit 1953) These measurements are complicated by the fact that extra vestibular sources of tonus such as voluntary fixation may inhibit or mask any changes in otolithic tonus Cycloversional movements cannot be made volun

tarily and therefore this factor need not be considered when measuring counterrolling

The principal aims of this investigation are threefold

1 Evaluation of a photographic technique for measuring torsional eye positions

2 Measurement with the above method of compensatory rolling eye movements in man as an index of the activity of his otolith organs placed in various positions in space Although the otolith organs quite obviously have a three dimensional arrangement the investigation of the effect of tilt of the head upon torsion has been limited to one plane (frontal) and for the most part to the upper two quadrants of this plane Tilting effects were therefore investigated not only in the frontal but in the sagittal and two intermediate planes ($\pm 45°$)

3 Development of a theory of the mechanism of otolith stimulation from information obtained from compensatory rolling movements and from known anatomical data

MATERIALS AND METHODS

In designing the apparatus and procedure for measuring reflex torsion of the eye associated with gravitational stimulation of the otolith organs several important improvements over previous arrangements have been made a method of recording and measuring rotary eye movements was developed which was more precise than previous methods an apparatus for rigidly supporting and accurately positioning a human subject was used fixation of the eye was carefully controlled to prevent torsion associated with oblique movements of the eye

Photographic method of recording counterrolling

A method involving photography of natural landmarks on the iris was devised to meet the requirement of increased precision It was felt that adequate natural landmarks normally exist on the iris which accurately reflect rotary movement of the eye A solution to the problem of measuring very small amounts of movement of these landmarks was found in simple magnification To achieve a high magnification a 35 mm reflex type camera fitted with bellows and a 135 mm lens was used to enlarge the film image of the entire eye to about twice the actual size This image developed as a transparency was further greatly magnified by projection through a 500 watt projector onto a radiant screen placed 20 feet away In this way an enlargement of over 300 times the actual eye size was obtained

An electronic flash unit was fitted with a cone shaped attachment for better control over the direction and amount of light emitted The light source was directed inward almost parallel to the subject s face plane and slightly upward which intensified the detail of the crypts folds etc in the iris Color film aided further in differentiating and increasing the contrast of the iris structures

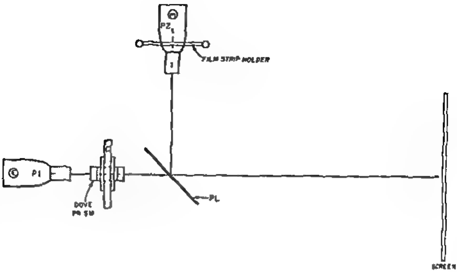

Fig. 1. Diagram of apparatus for measuring counterrolling.

The measurement of angular torsional movement around the center of the pupil was accomplished by superimposing upon each test image in succession a second projected image of the subject's eye as a standard of comparison. It was found by this method that relative rotary movement between the test or standard image was readily detectable. Free & Jones (1959, 1960) used a sketch of a few radial iris markings as their standard of comparison upon which a projected image of the iris was superimposed. Using this technique they were able to measure rolling eye movements to an accuracy of about plus or minus one degree.

The apparatus used to measure counterrolling is diagrammed in Fig. 1. The optic axes of two 500 watt projectors (*P1* and *P2*) were placed at right angles to each other and in a horizontal plane. A pellicle (*PL*) with a reflectance transmittance ratio of 1:1, placed in a vertical plane and at an angle of 45° to each projector rendered the projectors optically coincident. The resultant images were equal in intensity, size and detail. Rotation of one image relative to the other was accomplished by means of a prism device, a so called cyclometer (*C*). This instrument consists essentially of a dove prism mounted in a disc so that it can be rotated about its longitudinal axis. A direct reading double (plus and minus) vernier scaled in minutes of arc on the disc housing opposes the prism holder disc (10 in diameter) which is scaled in degrees of arc. The cyclometer was arbitrarily placed in a position to intercept the light rays from the projector containing the standard film. By use of the cyclometer the two projected film images could be aligned and the difference in angular position measured quite accurately down to one minute of arc.

Transporting the test film strips by means of commercial film strip holders was found to be much too inaccurate for such sensitive measures. As a result a film strip holder attachment was designed specifically for the projector used

and was constructed with extremely close fittings This attachment not only rigidly supported the film strip but also provided exact vertical and horizontal adjustments The film frame held between two glass plates on a spring loaded carrier could be moved quickly and precisely to align the projected images

The relative change in torsional position of the standard image indicated on the cyclometer scale was determined at least four times for each photograph Contrary to all previous methods in which movement of a single point or meridian of the eye was measured the present method uses the iris as a whole i e, aligning essentially all parts of the iris at once with no particular reference to any one part By this method normal fluctuations in pupil size incidentally recorded in the films did not appreciably affect the measurement of torsion When a significant difference occurred judgments in alignment were based upon a more peripheral smaller ring of iris Motion parallax of one image with respect to the other induced by repeatedly covering and uncovering one projector lens was used as an extremely sensitive method for final image alignment

Devices and procedure for positioning the subject in space

The Human Disorientation Device (HDD) (Fig 2) located at the Naval School of Aviation Medicine provided a very accurate highly rigid apparatus for rotating and positioning a human subject in three dimensional space The subject used for all experiments to be described was a healthy Navy enlisted male 20 years old This subject previous to these experiments had passed all physical examinations required by the Naval School of Aviation Medicine for volunteer research subjects The test enclosure of the HDD consists essentially of an eight foot diameter aluminum cylinder Mounted to the outer surface of this cylinder is a gear which provides movement in either direction around the horizontal axis Within the enclosure a seat is mounted which is adjustable laterally to control the width of the side supports and vertically as a unit The fixed position of the seat in addition can be moved about the vertical axis in 45° steps

A control desk contained all the necessary meters to indicate chair position and remote controls for altering this position

The need for precise camera adjustments imposed by a critical depth of field and limited field of view was met by a special camera and bellows support mounted in front of the subject With this apparatus the camera equipment could be precisely moved along the three major coordinates and locked in position (Fig 2) An overhead bar held the strobe spotlight in the position already described

Another major consideration in positioning the subject was the careful preparation of supportive appliances Even though the HDD chair provided certain body knee waist shoulder arm and leg supports it was found that for critical positioning experiments these measures were not adequate The subject was not completely immobilized slight movements of the head on

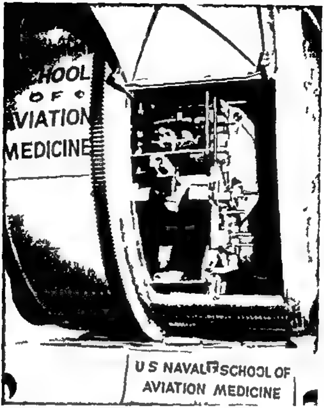

Fig. 2. The Human Disorientation Device with apparatus in position.

the trunk were still possible. Comfort also had to be considered since certain unusual body attitudes would have to be sustained over considerable periods of time.

Fortunately, it has been found that the comfort factor is directly proportional to the amount of support and exactness of fit. In an attempt to provide a strong, rigid, yet comfortable support, a fitted plastic head and body shell was fitted exactly to the subject. Negative back and shoulder casts were constructed with rapid setting plaster gauze bandages applied directly to the skin. The head cast, considered to be more critical, was formed with alginate dental material. The subject's hair was clipped close to the scalp to ensure an even closer fit to the skull. The positive forms of both the head and body were then cast with dental stone which has very minimal shrinkage. The head piece, shaped as a helmet, was formed with dental acrylic material approximately 3/8 inch thick to hold changes in form during processing to a minimum. The negative body support form was constructed with Fiberlas material 1/4 inch thick. The two finished components were refitted to the subject with some slight refinements such as relieving pressure points. Finally, hardware connections between the head and neck, the entire appliance and the HDD chair were bolted to the plastic material. A chin strap to keep the head vertically within the head piece and a girdle to constrain the trunk were added.

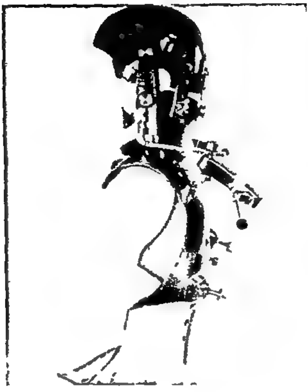

Fig 3 Molded head and body appliance (side view)

The appliance in its final form is shown in Fig 3 As a result of these devices the head body and HDD chair moved as a unit with no significant independent movement when the test enclosure was rotated and placed in any position

The procedure followed for each trial run was essentially as now described The molded plastic head and body appliance was fastened securely to the subject This appliance in turn was bolted tightly to the HDD chair The camera mount was swung into position in front of the subject and locked Then the positioning of the camera fixation target and strobe light were coordinated so that the eye correctly illuminated was imaged on the center of the cross hairs of the ground glass viewer The overhead lights were turned out which rendered the inside of the test enclosure dark except for the small fixation target light and a 50 watt modeling light inside the strobe unit The latter confined to the eye tested was found necessary to constrict the iris in order to reveal more landmarks Although the 50 watt light tended to fog the subject s vision by creating a veiling glare it is not known what visual influence upon torsional eye position might exist under these conditions

The test enclosure door was closed and two way audio signal communication was established The test enclosure was then rotated to the desired position at a velocity of less than 1 degree per second to avoid stimulating the semicircular canals to any appreciable extent (Dodge 1923) Complete revolu

tions of the test cylinder about the horizontal axis were made with stops at every 15 degrees. When 15 degree excursions were made, 60 second delays were timed after the vehicle had stopped before signalling the subject to ready himself. These time delays after stopping were increased to 120 seconds when greater than 15° rotations were necessary, such as returning to upright to reload film. The ready signal to the subject prompted him to fixate the target and to open his eyes as wide as possible. Only when these conditions were met did he return the signal. The camera with synchronized strobe flash was fired remotely; the motor drive advanced the film and wound the shutter in readiness for the next exposure. Exposures of up to one per second were made in this manner.

The subject was positioned at every fifteen degrees within the frontal, sagittal and two intermediate planes. In order to accomplish this movement with the HDD, the chair had to be repositioned about the vertical axis such that the antero-posterior body axis of the seated subject formed angles of zero, 45, 90 and 135 degrees with the horizontal drive axis.

The left eye of the subject was occluded for all tests to remove any binocular visual factors contributing to rotary eye movements such as cyclofusion or cycloversion associated with convergence.

Control of fixation

One of the earliest general criticisms of studies involving eye movement was the apparent lack of adequate control over or complete disregard for eye position. This concern over direction of fixation is justifiable since wheel motions of the eyes are also associated with oblique directions of gaze. In order to eliminate this possible source of error, a fixation target holder was mounted at right angles to the optic axis of the camera. This holder contained a photographic reproduction of a black Snellen letter "c" reduced in angular size to equal about 5 minutes of arc. The letter, placed upon an opaque white background 14 mm in diameter, was illuminated from behind by a 6 watt bulb. As a result foveal fixation was required for resolution.

The subject observed the fixation target by reflection from a pellicle (reflectance-transmittance ratio of 1:9) placed at a 45° angle between the camera lens and the subject's right eye. Adjustable connections on the target holder allowed centering the fixation letter within the camera lens which was illuminated for this adjustment.

RESULTS AND DISCUSSION

Precision of measurement of cyclorotation

Four or more attempts were made to align a standard photograph with each of the photographs taken in the course of this study. By comparing each photograph with the standard, it was possible to determine the amount of cyclorotation involved. For each of these photographs an average reading

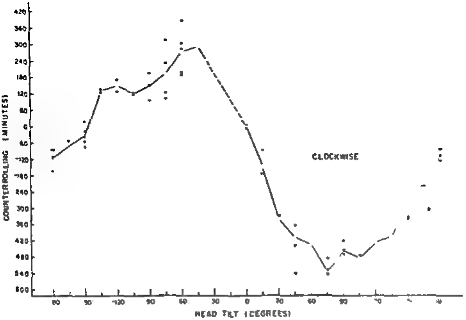

FIG. 4. Counterrolling data of one test run showing typical variability of response

was determined. The mean deviations from the average ranged from zero to fourteen minutes of arc, with the average falling at 5.[illegible] minutes of arc.

Tilting the body and head as a unit

Fig. 4 illustrates the type of data found in the case of lateral head (body) tilt. In this particular set of data measurements were made at every 15°, starting at zero and proceeding in a clockwise order through a complete cycle. When such a series had to be interrupted, usually because the camera ran out of film, the subject was rotated back to the starting position. After changing film, etc., he was rotated again to the point at which the interruption occurred. A two minute interval was then allowed before proceeding to further measurements.

At each of the various head tilts, two or more photographs were taken. Photographs which were not properly exposed for such reasons as eye blinks, strobe light and camera failures had to be excluded.

Fig. 4 demonstrates one important characteristic of the data, namely that there is a constant fluctuation in counterrolling. This is indicated by the separation of the points for the various photographs taken at each of the various positions. The typical range of this variation is in the order of about one degree, but occasionally even greater variability was found. Furthermore, since a very small number of photographs were taken at each position, the line connecting the averages is by no means smooth giving further evidence of variability from moment to moment. Variability of response measured for a given individual has been reported by other investigators: Grahe (1927–1928)

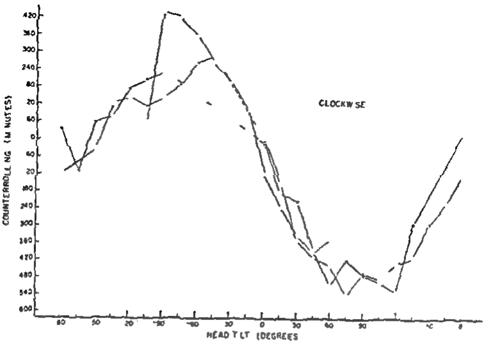

Fig. 5. Counterrolling as a function of lateral head tilt. The order of measurement proceeded from zero in 15° steps in a clockwise direction.

claimed, for example, that because of this fluctuation of response several measurements are necessary for determination of the mean angle of rotation. Fischer (1927) also encountered temporal fluctuations, which he displayed in his graphs by plotting the minimal and maximal values instead of the average values found. Graybiel & Woellner (1959) regularly observed significant spontaneous variations in torsional eye position of their subjects.

One possible factor contributing to these fluctuations is the normal physiological unrest of the eye. Fender (1955) using a contact lens fitted with a small mirrored stalk, has studied torsional motions when fixating an illuminated pinhole subtending one minute of visual angle. Despite the fact that all excursions of fixation recorded were less than ten minutes of arc, Fender found random torsional movements. However, the extent of these movements was small and did not exceed eight minutes of arc even during flick movements of 20 minutes of arc.

The greatly magnified film recordings used in the present study indicated that fixation was not appreciably in error. This was demonstrated by the fact that the corneal reflex of the strobe light remained in the same position relative to the limbus. Furthermore, resolution of the fixation target which was apparently achieved prior to each recording of eye position, required that fixation be accurate within one degree. Therefore it appears that variability of counterrolling response found in the present experiment cannot be explained by variations in fixation.

Fig. 5 shows the results of repeating the experiment recorded in Fig. 4

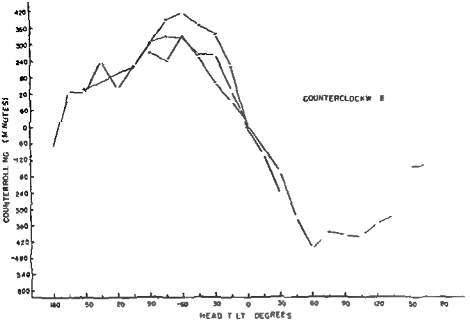

FIG 6 Counterrolling as a function of lateral head tilt The order of measurement proceeded from zero in 15 steps in a counterclockwise direction

three different times Qualitatively the curves are quite similar the rise peak and fall of the individual curves occur always in the same direction and within essentially the same ranges of body tilt from the zero (upright) position However quantitatively significant differences far greater than the small measuring error occur from curve to curve It appears as if some gain control mechanism varies the overt response to tilt

Fig 6 shows similar data obtained with the order of measurements reversed (counterclockwise)

Fig 7 portrays the average data for the clockwise and counterclockwise order which are presented in detail in Figs 5 and 6 The measurements were made in both the clockwise and counterclockwise order to ascertain whether the previous history of tilt has any significant effect upon counterrolling Fischer (1930) found some evidence to indicate a possible difference in counterrolling response between the clockwise and the counterclockwise order of making measurements However the variability of his results prevented him from drawing any conclusion It seemed important to determine if a residual effect from tilting does exist If it does then in looking for an explanation of counterrolling not only must the attitude of the otolith organs with respect to gravity at a given moment be considered but also the attitudes that had existed in the period immediately preceding the measurement

From the data plotted in Fig 7 it appears that the otoliths as indicated by these counterrolling data are not differentially affected by the order in

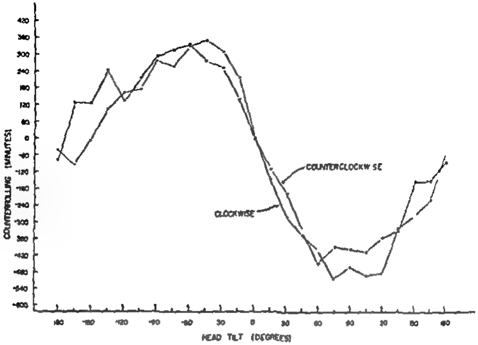

Fig. 7. Average clockwise and counterclockwise data. Closed circles represent average of data in Fig. 7, open circles average of data in Fig. 8.

which the measurements are made, but only by the actual position of the head and body with respect to gravity at the moment of the recording. On the basis of this finding all data found for lateral head tilt were combined without regard for the order in which the measurements were made.

Each of the open circles in Fig. 8 represents the average of all the counter rolling values in Figs. 5 and 6 which have the same abscissa value. The general form of the curve agrees with that found by Fischer (1930) in his subjective after image method. The average torsional movement appears to increase steadily and regularly in a direction opposite body (head) tilt. This constitutes a compensation by the eyes for the change in lateral head position. It can be readily seen, however, that the ratio of eye to head rotation is quite small, a fact reported by W. Nagel (1896) and several other early researchers. If the head is rotated beyond a certain point (between 60 and 90 degrees) the compensatory movement begins to decrease more slowly than it built up, the eye finally returns approximately to its original position within the eye socket (zero torsion) when the subject is placed in a head down attitude ($\pm 180°$ body tilt). This general description holds true for the counter rolling response to tilt in either direction. However, from the graph it would appear that there is a difference in peak response, i.e., the right eye seems to respond more to tilt toward the right side. This is important because if the two eyes receive a different amount of tonic innervation for cycloversion one would expect a change in the cyclophoria, with its attendant problems, to occur whenever the head is tilted. Fischer (1930), on the other hand, reported

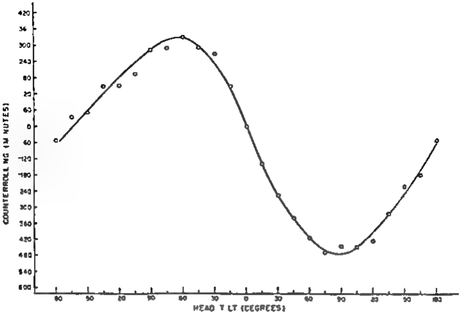

Fig. 8. Average of all counterrolling values for lateral head tilt.

greater counterrolling of the left eye in an inclination to the right, but because of the variability of his findings he declined to make any definite assertion about the right eye measurements.

In Fischer's and the present study a great deal of importance must be attached to the value of counterrolling assumed to be absolute zero. All subsequent measurements are referred to this particular value. Any difference in the assumed and actual absolute zero torsional position will be reflected in a vertical shift of the entire curve. If one assumes, therefore, that the absolute zero in the present study lies at the relative value of about minus sixty minutes, the plus and minus segments of the curve become nearly symmetrical with the peak values essentially equal (about seven degrees). However, the question of differential otolithic innervation to the two eyes must remain unsettled until binocular studies are made.

The eyes are not limited by their anatomical arrangement from rolling greater amounts than indicated in this study. Woellner & Graybiel (1959) found that counterrolling increased substantially when the magnitude of the stimulus (inertial force) was increased in the human centrifuge.

The effect upon torsional position of the eye of changing the attitude of the otolith organs in a tumbling direction is shown in Fig. 9. The different curves represent data obtained in different runs starting with the head erect and tumbling through one complete cycle, forward in some cases and backward in others. The average data for all runs is shown in Fig. 9. These results show no definite trend in torsional response to tilt in this plane. The relatively small random variation in the data can be attributed to the temporal fluctuations discussed previously.

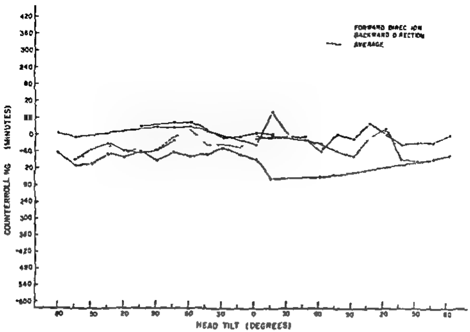

Fig 9 Counterrolling as a f nction of fore an l aft hea l tilt

Tilting the whole body in the two intermediate planes provoked counter rolling (Fig 10) The curves in this figure are based on data from single runs in which the subject tumbled forward through one cycle in each of the oblique planes The mode of response to tilt was quite similar to that found in the frontal plane although comparatively somewhat lower in amplitude

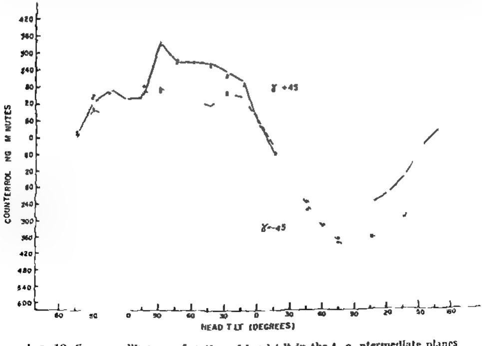

Fig 10 Coun lling as a function of head t lt in the t o ntermediate planes

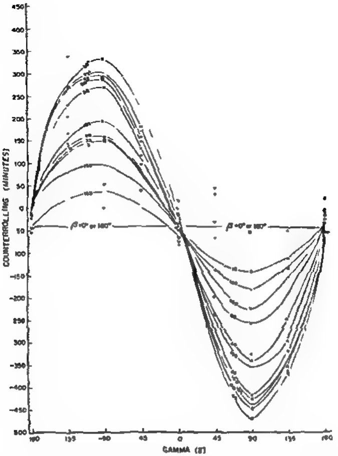

FIG 11 The resultant family of beta curves as a function of gamma

Comparison of the right and left intermediate plane data plots reveals a vertical shift of one curve with respect to the other This apparent difference in the two curves based strictly upon the choice of a zero torsion position, disappears when the curves are vertically adjusted

The above studies provide data of the activity of the otolith organs contributing to compensatory eye movements around the lines of sight, when these organs are tilted at every 15 degrees within four different planes From these data it should be possible to predict by interpolation the counterrolling response for any position of the head in space

A possible scheme for consolidating the counterrolling data could consist in the use of two variables (1) angle β, degree of tilt of the cephalocaudal axis of the body about the horizontal axis of the tilting device, and (2) angle γ, degree of rotation of the body around its cephalocaudal axis Angle β varies from zero (position in which the vertical axis of the head coincides with the gravitational force) to -180° (head down position), angle γ can be varied plus or minus 180° from zero (median sagittal plane of the head perpendicular to the horizontal drive axis) The resultant family of beta curves depicting

counterrolling as a function of gamma are shown in Fig 11 In each of these curves the average counterrolling values were fitted empirically with a smooth curve The curve for a beta value of 90° is of special interest because it represents the case in which the cephalocaudal axis of the subject is kept horizontal and the subject is rotated around his cephalocaudal axis like a roast pig on a spit

The absence of appreciable counterrolling when the head is tilted in its sagittal plane does not justify any inference that compensatory eye reflexes arising in the otolith organs do not exist when tilting in this plane On the contrary Sullivan *et al* (1956) De Wit (1953) and others have shown that the eyes move reflexly in a vertical direction directly counter to the fore and aft tilting of the head

In the present experiment the subject was directed to fixate a target straight in front of his face Any innervation from the otoliths tending to elevate or depress the eyes induced by pitching the head in a fore and aft direction would have been compensated by counter fixational innervation

If a man is flat on his back and rolls his head around its cephalocaudal axis this could induce a reflex change in azimuth of the lines of sight but this would also be compensated by the counter fixational innervation

These effects are readily observable in an animal like the rabbit which possesses no voluntary fixation (Cogan 1956)

Theory

The mechanism of otolith stimulation

The effective stimulus to the otolith organs is generally agreed to be the force of gravity However the manner in which these organs are stimulated by gravity has not been established Three general theories as to the possible modes of action of gravity upon the otoliths have been advanced pull or traction (Magnus de Kleyn 1921) pressure (Quix 1923) or gliding movement (Breuer 1891) While each of these theories has its supporters none can explain all of the known facts In addition to this a great deal of controversy exists over whether one of the pairs of otolith organs (saccules) has any equilibrial function at all

In an attempt to resolve these and other problems concerning the otolith mechanism the writer used data from the present and past studies in developing specific concepts as to how the otolith organs respond to gravity The validity of these concepts however must be tested by further human and animal studies The conclusions in the following discussion therefore are to be regarded as forming a working hypothesis subject to revision as more data become available A recent follow up study (Miller to be published) using several normal subjects tilted through $\pm 75°$ in the frontal plane revealed counterrolling response curves quite similar in form to those presented above

It is proposed that each otolith can be stimulated only by a shearing force applied inwardly i e toward the median sagittal plane This unidirectional

response furthermore reaches its maximum when the direction of the force is parallel to the plane of the otolith organ Evidence for unidirectional activation of the otolith is provided by reports that counterrolling in humans with unilaterally defective labyrinths is manifested only when the head is tilted toward the defective side

This theory in certain respects conforms with the theory of Breuer in which the gliding directions of the otolith is that of its macular planes These planes he assumed to be in a frontal section horizontal for the utricles and vertical for the saccules The effect of gravity on the nerve endings he claimed to be proportional to the sine of the angle between the gliding direction and horizontal Breuer also proposed that the otoliths (cilia) could be stimulated in opposite directions giving rise to behaviors that were the reverse of each other

At this point it might be well to consider the anatomy and topography of the otolith organs and attempt to correlate this information with the physiological data The receptor cells in the macula of each utricle and each saccule are arranged in a layer These structures are paralleled by a layer of gelatinous substance containing calcium carbonate crystals called otoliths or statoliths These crystals have a higher specific gravity than their surroundings and thus respond to gravity Between and more or less perpendicular to these layers are found cilia (filaments emerging from the sensitive cells) Activity (measured by counterrolling) of the receptor cells is assumed to be stimulated by a unidirectional shearing of the cilia as a result of inward movement of the statoliths The activity of the macula is assumed to reach a maximum when the force (gravity) is parallel to the layer of receptor cells and directed toward the median sagittal plane

The utricular and saccular otoliths are oriented to each other and to the skull in a particular manner Unfortunately detailed topographical data are not available The studies of Quix (1923) and de Burlet (1923 1924) however do provide data for constructing a working model that is adequate for this discussion The location of the macular planes of the saccule seems to be generally agreed upon by various authors and is portrayed in Fig 12 according to Quix s data The location of the maculae of the utricles on the other hand is less definite The histological operation causes many alterations especially in the utricle This component does not rest as does the macula of the saccule upon a bony layer but upon a membrane separating the utricle from the cisterna perilymphatics (van Egmond 1940) The plane of the utricle is approximately horizontal as Breuer stated However de Burlet indicated a slight upward inclination while Quix described a slight downward slope of these planes from the midline Since the data and thus the theory predict a slight upward slope (about six degrees) of the utricles from horizontal (Fig 12) it is so considered in this discussion The maculae of the otolith organs in Fig 12 all lie in planes perpendicular to the frontal plane of the head It is important to note the position of the statoliths relative to the macular planes in the saccules they are lateral in the utricles superior

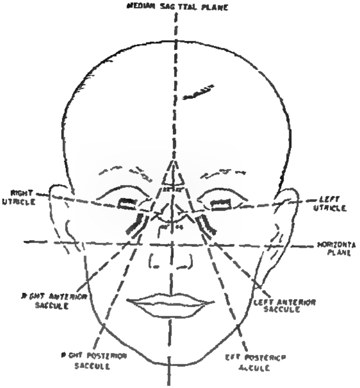

Fig. 12. Schematic drawing (frontal section) of the topography of the utricular and saccular maculae.

To say that the receptor cells lie in flat planes is an approximation, since the actual macular surfaces are somewhat curved.

An important aspect of the general theory, as will be explained later, is the assumption that for certain orientations of the head the saccules are sensitive to the force of gravity and contribute to the counterrolling response of the eyes. It is therefore proposed that counterrolling impulses to the extraocular muscles arise from the following sources (in addition to the possible receptors in the neck): the right and left utricles, the right and left anterior saccules, the right and left posterior saccules.

The fact that the right otolith organs produce counterrolling only in a clockwise direction and conversely the left otolith organs only in an anti-clockwise direction has already been mentioned. This probably means that either the movement of the otoliths is mechanically restricted in all directions except inward or the stress on the hair cells in one direction only will excite a nervous discharge, such as found by Lowenstein & Sand (1936) in the cupula of the semi-circular canals of elasmobranchs.

From Fig. 12 it will be seen that in order for any of the six otolithic components to be stimulated at all, the inward direction of the macular plane must fall within plus and minus 90° from the direction of the stimulating force (gravity in this study). The amount and direction of counterrolling will depend, according to the theory, upon the algebraic sum of activity con-

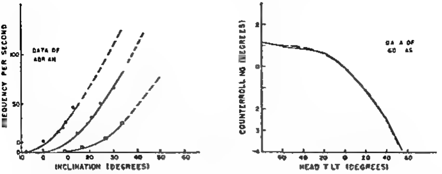

FIG 13 Data of Adrian and Gollas fitted with cosine square function curves

tributed by each component falling within these two quadrants For example in the position illustrated in which the head is erect the saccular components would fall outside the active zone (+90°) and therefore would be expected to have no effect on counterrolling The utricles on the contrary would be activated However no change in torsional position would be manifested since the stimulation from each utricle is equal and opposite in effect in this case Before the effect of other positions can be evaluated it is necessary to establish the relative contribution of each otolithic component Since relatively few measurements were made in the intermediate planes and the variability of response is considerable the following analysis is limited to the lateral plane data

Let us assume that the otolith response as measured by counterrolling is some function of the angular displacement (ϕ) of the inward direction of the macula from the force of gravity Woellner & Graybiel (1959) gave evidence that counterrolling is directly proportional to the magnitude of force acting laterally on the head within the range of 1 g If the response were proportional to the gravity component parallel to the inward direction of the macula then the response would be proportional to cosine ϕ But this simple relationship does not appear to conform to the data The structure of the otolith organ apparently is such as to dampen the effect of gravity and to yield a function in which the response is nearly proportional to cosine square ϕ As indicated above the response is zero for values of ϕ greater than 90 In the case of lateral head tilt let us designate the angle of tilt α as the angular displacement of the cephalocaudal axis of the head from vertical Then equations for counterrolling (ψ) for various degrees of lateral tilt can be written as follows

$$
\begin{aligned}
\psi_T = \psi_U - \psi_S = {} & U_R\cos^2(84-\alpha) - U_L\cos^2(276-\alpha) \\
& SA_R\cos^2(134-\alpha) - SA_L\cos^2(226-\alpha) \\
& SP_R\cos^2(158-\alpha) - SP_L\cos^2(202-\alpha)
\end{aligned}
$$

where ψ_T is the total amount of counterrolling (sum of utricular ψ_U and saccular ψ_S components) and where U_R U_L etc represent the maximum amount of counterrolling contributed by each macula

An interplay between the opposing activity of the utricles would occur

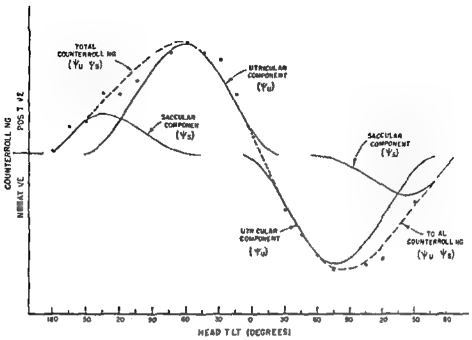

Fig 14 Data of Fig 10 fitted with cosine square function curves

according to the theory around the upright position (about ±6°) Consequently it is impossible to assess the function of each pair of utricular otoliths near the upright position when both are active

Adrian (1943) recorded potentials in the vestibular nuclei of cats When these animals were tilted laterally in one direction the frequency of nerve impulses increased in the opposite direction no increase occurred indicating that otolith activity on one side only was being recorded His data therefore indicate the manner in which the activity of one utricle reaches its zero level It was found that Adrian s data (plotted in Fig 13 as open circles closed circles and squares for three different specimens) could be fitted quite satisfactorily with cosine square function curves (Fig 13) which differed only slightly from Adrian s original curves However the limited data prevent a complete test of this hypothesis for greater angles of tilt Similar evidence was obtained for man by referring to those investigations involving unilaterally defective labyrinths If the arbitrary position of zero as mentioned above assumed by Gollas (1936) is shifted in a vertical direction most of his data on several subjects reveal the same leveling off effect near the upright position As portrayed in Fig 13 a typical counterrolling response curve (solid line) reported by Gollas is approximated by a cosine square function curve (broken line)

On the basis of this evidence a cosine square function curve was fitted to the data found in the present study Beginning at the upright position the facts learned from the aforementioned data were taken into account by shifting the initial point of the curves inward so that they would overlap in the

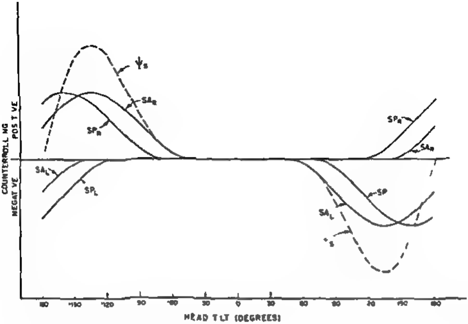

FIG. 15. Theoretical counterrolling contributed by the four saccular components as a function ($\cos^2$) of lateral head tilt.

horizontal direction by a slight amount (Fig. 14). A theoretical ($\cos^2$) curve approximated the curve fitted empirically to the data up to the maximum values but beyond these points an ever increasing gap developed between them. In order to explain this discrepancy it was necessary to postulate that either the function was not cosine square or other factors were also involved. The theory already outlined above provided a solution to the dilemma. If one considers that the saccular otoliths contribute to the counterrolling response, then the pieces fall into place surprisingly well. A cosine square function was plotted for each of the four components of the saccular apparatus (Fig. 15). An arbitrary and equal value was chosen as the maximum for each component. The resultant curves were plotted according to the topographical data above and the "inward shearing" theory. Although the position of the individual and the combined "saccular" curves were more or less fixed on the x axis (head tilt), the scale (y axis) of the curves was adjusted to give the best fit when the "saccular" and "utricular" components were summated. The resultant curve (Fig. 14) appears to give a satisfactory fit to the data. Thus, the saccules when activated would appear to contribute a smaller yet significant effect upon counterrolling.

Failure to detect positive findings has been inferred by many in the past as proof that the saccule does not respond to the force of gravity. The fact that a saccular response to tilt has not been found in these studies is not surprising in light of the new theory. According to this theory one would not expect the saccular components to be active at all until the angle of tilt of

the body reached about +44 degrees and active maximally until ±134 degrees. No known studies which have attempted to differentiate saccular and utricular function have dealt with the effects of tilt within these regions. On the other hand, certain positive evidence is available in the literature to show that the saccular otolith functions as part of the equilibrial system (*Hasegawa 1937, Jongkees, 1950, Lyon 1951*).

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ZUSAMMENFASSUNG

Eine photographische Methode zur Messung von Augendrehbewegungen (Gegenrollung) ergab im Durchschnitt eine Genauigkeit von ±5.3 Bogenminuten. Bei Anwendung dieser Methode wurden Augendrehbewegungen, die fur Kopf- (Rumpf-) Neigung kompensieren, in allen untersuchten Ebenen mit Ausnahme der sagittalen gefunden. In den zwei Zwischenebenen (±45°) war die gesamt Gegenrollreaktion ähnlich und etwas geringer als im Falle der Seitenneigung. Gegenrollung erfolgte immer entgegengesetzt zur Seitenkomponente der Kopfneigung und nahm ziemlich rasch zu bis zu einem Maximum bei einer Kopfneigung von 40° bis 90°. Von diesem Punkt an nahm die Gegenrollung ab, aber langsamer als sie zugenommen hatte, und erreichte ungefahr Null, wenn der Kopf senkrecht nach unten gehalten war. Ein Unterschied im absoluten Betrag der Drehbewegung des rechten Auges beim Neigen des Kopfes (Korpers) nach links oder nach rechts konnte nicht festgestellt werden. Doch konnte kein Unterschied in der Gegenbewegung (im Uhrzeigersinn und gegen den Uhrzeigersinn) der Reihenfolge der Messungen zugeschrieben werden. Schwankungen in der Gegenrollung waren betrachtlich bei jedem Grad der Neigung. Eine Theorie zur Erklarung des Mechanismus der Anregung des *Otholith Organs* wird unterbreitet.

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U. S. Naval School of Aviation Medicine
U. S. Naval Aviation Medical Center
Pensacola, Florida, U.S.A.

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ALLERGIC FACTORS IN THE PATHOLOGY OF THE PARANASAL SINUSES

A I ASIEWICZ
London England

Histological examination of the biopsy mucosa in chronic maxillay and ethmoidal sinusitis showed the metaplastic superficial epithel al layer with thickened low columnar cells and increased numbers of basal and goblet cells The connective tissue revealed fibrous contraction causing atrophy of the once hypertrophied mucous glands and blood vessels surrounded by lymphocytes plasma cells eosinophils and histiocytes In 3 % of cases of allergic maxillary sinusitis the thickened basilar membrane was found to be oedematous with eosinophilic infiltration The adjacent bony wall showed osteoporotic changes more frequently within the ethmoidal cells Any infection increases the oedema causing polyp formation obstruction of the sero mucous glands with the lool of one cystic shape and fibrosis of blood vessels Subsequent atrophy is responsible for a granular appearance of the sinus mucosa mentioned

The tendency of the mucosa of the upper respiratory organs to produce allergic manifestations is owing to its considerable surface exposed to contact with allergens The significant vascularisation of this mucosa contributes mainly to its role as the one target organ (Erfolgsorgan) for a number of far reaching exo and endo allergens Therefore we may distinguish two principal forms of clinical symptomatology in the course of vasomotor rhinitis on an allergic basis The first takes the form of attacl s of sneezing endonasal itching muco serous secretion and some degree of nasal respiratory obstruction followed by symptom free intervals which are elicited often by various exogeneous allergens The second consists of two or more attacl s of sneezing profuse mucous discharge intense itching and prevalence of nasal stenosis which alternates from one side to the other still persistent even in the intervals between the attacl s The patient complains also of head aches in the frontal region connected with light facial oedema and urticaria These symptoms give rise to suspicions of food allergy and must be differentiated fr m other forms of neurovegetative disturbances of the nasal mucosa (Bickel 1952) Because of the settlement on the surface of the upper respiratory organs by a number of symbiotic as well as morbific microorganisms we are justified in assuming that virus infection may promote the invasion of different ba teria including *Haemophilus influen ae* into the deeper parts of the nas l muc sa Any form of allergic condition of this mucosa both atopic and non atopi is responsible for spreading infection towards the sinuses because f oed matous thicl ening of mucosa around its ostia which become

easily obstructed This promoting action is obviously supported by attacks of sneezing reduction or loss of ciliary activity and changes in the watery secretion the pH of which is slightly increased besides the altered bacterio static action of its lysozymes (Flemming) Allergic conditions of the nasal mucosa are often elicited by different allergens directly inhaled or spread from a focus of microorganisms situated in the neighborhood of the nasal cavity i e the paransal sinuses granulomas of the premolars and molars of the upper maxilla or the tonsils and adenoids (Eckert Moebius 1950 Mitter maier 1933 1938 Zange 1957 Berendes & Schellock 1955) In the latter event we are faced with the bacterial sensitisation of the mucosa in question in which skin testing gives early positive reactions to staphylococci *Streptococcus haemoliticus* and pneumococci (Hlavacek & Lojda 1959) Allergic reactions depend upon the kind and amount of allergens as well as the degree of sensitivity of the nasal and sinus mucosa the responses of which vary from a small one to a marked inflammation defined by Kline Koch Herberts Stromme and Larroude as hyperergic atopic reaction This process is characterised by rapid onset violent course and a slower resolution Mild acute infections play a great part in the formation of permanent changes so that the inflammatory process precominates in the histological picture darkening somewhat that of the allergy Acute exacerbations of chronic sinusitis with mucous discharge have in 70% of cases always a vasomotor allergic background likewise recurrences of nasal polypi with a hyper esthetic allergic origin (Giertz & Hahn 1959 van Dishoeck & Franssen 1957 Stromme) Pink pale mucous membrane associated with oedematous polyps in the middle meatus is a common rhinological picture in recurrent allergic sinusitis while the profuse nasal secretion as well as different parts of the mucosa in question contain a number of eosinophils The mechanism of attraction of eosinophilic cells in vasomotor rhinitis and chronic sinusitis is according to Voorhorst the disintegration products of proteins accumulated in large amounts in allergic circumstances besides the allergen reagin reaction in which histamine is liberated (Hussarek 1958) This opinion is supported by the appearance of mast cells in large quantities in the super ficial and deeper parts of the nasalsinus mucosa (Messerklinger 1955 1957) Globulinic antibodies called reagine accumulated mainly within the en dothelial cells of the blood vessels are responsible for the prompt reaction But the delayed form of this reaction seems to be called forth by the agens stored up within the sensitized lymphocytes Changes in all sheets of the given sinus wall depend mainly on the type of infection (*Streptococcus haemoliticus Staphylococcus (aureus albus)* pneumococci) while in more protracted cases of this type of sinusitis there occur early changes in supply to the blood vessels which appear dilated and congested Lymphocytes eosinophils plasma cells monocytes and histiocytes form one infiltration The perivascular spaces become oedematous as in the antigen antibody atopic reaction which confirms the supposition of the defensive insuf ficiency of the tissues in question Any repeated inflammation tends to form a

Allergy	*Infection*
Mucosa Pale pink	Oedematous thickening with polypoid formation
Epithelium Simple swelling or thickening	Sporadically metaplasia with squamous proliferation and partial destruction
Vibratory cilia near the ostia n Shows fragmentary destruction	Shows widespread destruction connected with metaplasia of the epithelium
B M Thickened	Thickened to wide layer with sometimes hyaline appearance
Secretion Watery and mucous	Muco purulent with a number of eosinophils neutrophils slightly increased pH and variable isotonicity
Subepithelial layer Oedema	Fibrosis in varying degree
Glands Increased in number	Dilated with cystic formation marked discharge of pus mixed with mucous secretion sporadically compressed glands connected with fibrotic atrophy
Blood vessels Increased in number and dilated	Thickening of its walls here and there may have thromboses of arteries veins and lymphatics sporadically dispersed capillary destruction of its walls
Cellular infiltration Considerable number of eosinophils moderate infiltration with lymphocytes	Marked infiltration with neutrophils monocytes histiocytes fibroblasts and sclerotic changes are to be found there
Submucous fibrous tissue Tends to form oedema and mesothelial cysts	Infiltration of polymorphonuclear cells sporadically sclerotic changes
Perichondrium and bone periosteum Thickened	Here and there bone sclerosis and osteomyelitic changes with partial osteoporotic ulcerations

new fibrous tissue associated with polypoid formation and thrombosis of the small vessels (Engston 1957)

In 70 cases of chronic maxillo ethmoidal sinusitis uni as well as bilateralis with an allergic background treated by me during the last 16 years there were 10 children (from 8 to 13 years) 42 men (from 17 to 52 years) and 18 women (from 21 to 50 years) In particular persons who had a family history of allergy could be divided into the following groups (1) Those who had previously had some allergic manifestations and at the same time showed little evidence of active symptoms only (25% delayed type of reaction) (2) Those who have a manifestation of allergy at certain periods and therefore may be defined as being in a balanced allergic state (20%) (3) Others (1(%) in whom the allergic symptoms from the upper respiratory organs were fully developed and the provocative skin tests on the extracts of house dust rye rice flour milk and cotton (Bencard standard tests A3 and A10) were positive (+) In all these cases washing out of the maxillary si

Fig. 1

Fig. 2

Fig. 1. Lipiolography of the maxillary sinus in a case of a 30 year old man (L. J.) suffering from perennial allergy; the negative contours of polypoid formation in the sinus mucosa.
Fig. 2. Section through the polypoid formation mentioned. Staining with haematoxylin eosin. Magnification ca. × 250.

nuses gave a mucoid secretion, more or less greyish in colour, in which a number of lymphocytes and eosinophils was present. Bacteriological examination reveals *Staphylococcus* (*aureus* and *albus*) in 40% of the cases, *Streptococcus haemoliticus* in 8%, Pneumococcus in 27%, *Micrococcus catarrhalis* and *Streptococcus non haemoliticus* in 50%. As regards the structural changes in different parts of the sinus mucosa in the course of the sinuitis in question, biopsy specimens taken from this mucosa near the ostia natur. of the maxillary sinus show the metaplastic superficial epithelial layer, the cilia of which were destroyed. Connective tissue reveals fibrous formation slowly contracting and causing atrophy of the primary hypertrophied mucous glands and blood vessels. The latter are surrounded by lymphocytes, plasma cells with strong pyroninophilic plasma, proving abundance of ribonucleic acid, eosinophils, monocytes and PAS positive histiocytes. Within the adjacent bone wall we find often osteoporotic changes with subsequent reabsorption. Thickened and swollen antral mucosa, together with neighbouring periosteum, is usually associated with papillary hypertrophy (see Figs. 1 and 2). One of the polypoid formations removed from the middle turbinate in one case revealed, after staining by the method of Jabonero, a number of anastomosing silver positive processes of cells of various shapes, surrounded by leucocytes and eosinophils. These elements are to be considered as vegetative formations with special

Fig 3 The same case Nasal polyp stained by a method of Jabonero High magnification ca × 750

reference to the capillary vessels Majer (1952, 1959, 1960 1961) showed the presence of a number of argentafin granules within these cells which is to be regarded as a symptom of its secretory activity (see Fig 3) In this form of chronic sinusitis the covering epithelium becomes irregular and its low columnar cuboidal cells show augmented thickness so that the number of basal cells is remarkably increased, as well as that of the goblet cells between the islands of the ciliated cells This particular seems to confirm the suggestion of the degenerative nature of these cells The basal cells possess the ability to form either ciliated or goblet cells The basement membrane in 4% of the cases examined showed allergic maxillary sinusitis and was thickened and associated with *eosinophilic infiltration of the oedematous tunica propria* After staining with Loeschke Muller solution collagenous fibres including hyaline like masses appeared clearly as an element The presence of PAS (leucofuchsin sulphite) positive reticuline fibres proves its abundant content of mucopolysaccharides (see Fig 4) Krama & Urbanek (1961) stated that the basement membrane is built up of PAS positive reticuline fibres, which proves that it has plenty of acid mucopolysaccharides It joints the homogenised layer of the oedematous connective tissue which is PAS negative but contains a considerable number of eosinophils and plasmatic cells The membrane is traversed by a number of fine channels running mainly in a vertical direction It looks like bright coloured strips about 1 6–4 μ in diameter forming here and there transverse communications (channel network) as well as funnel shaped enlargements directed towards the epithelial layer In several cases the difference was striking between the distribution of the mast cells in the peripheral and deeper parts of the chronic hyperplastic nasal mucosa with and without polypoid formations where the tint of its granula is more intensified to red and dark blue It is believed that these granula are the de

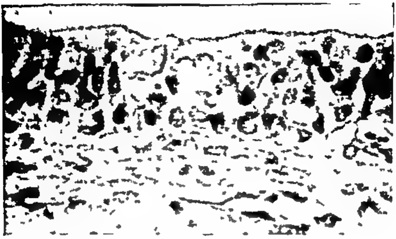

FIG 4 Biopsy specimen taken from the maxillary sinus mucosa near its natur ostia in a man of 41 suffering from perennial vasomotor rhino sinusitis PAS staining shows the structure of the B M

positors of heparin, lecithinase A and histamine (Wilander, Benditt, Riley) The homogenisation of the basic substance of the subepithelial layer makes impossible any regular exchange of matter between the blood vessels and the tissue elements Hypercrynia of glands and the prestatic fullness of blood vessels are responsible for serous exsudation and homogenisation of the collagenous tissue below the basement membrane An oedematous process caused by increase in permeability of the capillary network just beneath the basement membrane involved the stroma of the fibrous tissue within the subepithelial layer and the periosteum, forming papillamotous enlargements of the mucosa and even polypoid formations According to Weisskopf and Burn, the *response of the connective tissue to allergic or infections injuries is* characterised by a large amount of acid mucopolysaccharides, increase of fibroblasts and capillaries and degeneration of collagenous fibres suggesting that primitive mesenchymal endothelial cells are active in the formation of ground substance which is found to be interwoven with reticulinic fibres as Hlavacek & Lojda have pointed out Polymorpho nuclear cells are induced by polypeptides (α amino group) which are mediators of bacterial chemotaxis Coincidence of changes in nasal mucosa with adverse life and occupation situations such as hyperemia hypersecretion and swelling connected with obstruction of the nose, can be produced by cholinergic impulses transmitted by the parasympathetic nerve endings and might readily encourage development of nasal polypi especially in patients with impaired autonomous regulation As for the focal infection its anatomo pathological background has been established by I Glass, Passler, Rossle, Eckert Moebius, Mittermaier, Vogel, Zange and Berendes These authors consider that the infected focus of the teeth roots the tonsils and adenoids as well as the sinuses, acts like antigen by its prolonged sensitization spreading to various organs of the body This point of view was confirmed by experimental and clinical

observations by Koch, Herberts, Wullstein, Rauch and Kohler. In the ethmoidal cells, however, the levels of different fibrous tissue are loosely bound together and are therefore particularly prone to form an oedematous formation, while the blast of inspired air reaching first the ethmoid region is responsible for its irritation by dust and various allergens. Subsequent oedema of the anterior ethmoidal cell mucosa may be transitory, as occurs in periodical hay fever, but any infection increases the oedema, causing formation of the polyps, which depend on the degree of sensitivity and a certain inherent property of the mucosa. In the chronic types of allergy acute exacerbations of the sinusitis appear in recurring cycles and the oedematous process tends to become permanent, especially when any infection complicates its clinical course. Within these oedematous areas the eosinophils appear scattered throughout the tissues, mainly around the glands and beneath the basement membrane. The inflammatory infiltration with subsequent further fibrosis of supporting tissues is responsible for obstruction of the seromucous glands at their outlets, while cystic formations of various size were encountered there. The diminished blood supply as a consequence of thickening and fibrosis of the blood vessels produces atrophy of the mucous membrane and simultaneously contraction of the developed fibrous tissue, causing a granular appearance of its surface. Thickening and infection of the periosteum may lead to osteomyelitis occurring frequently in the ethmoidal and frontal sinuses. It is obvious that allergic manifestations like rhinitis allergica, asthma bronchiale and oedema Quincke improve considerably after elimination of the infected focuses within the mouth, pharynx and sinuses, as one of the predisposing factors in provoking the diseases mentioned (Hansen, Scheiffarth, Stromme, Larroude, Berendes). On the other hand, many of these allergic manifestations appear clearly as well as disappear easily after one general infection of the organism or any local inflammation connected with elevated temperature. Likewise traumatic injuries or surgical operations act in the same manner as regards their influence on the disturbances in question. The explanation of this fact is given by Seyle's theory of the stress and adaptations syndrome, according to which any strong and unspecific stimulus is responsible for pouring out glucocorticoids from the adrenal cortex ("alarm reaction"). Histochemical and biochemical studies on the behaviour of soluble and insoluble components of the connective tissue and the ground substance of the nasal mucosa, its polypoid formation, as well as electrophoretic anaysis of its extracts with staining for proteins and mucopolysaccharides in different stages of evolution is the most promising approach to the solution of the allergic problem of the respiratory organs.

ZUSAMMENFASSUNG

Histologische Untersuchungen der Nebenhohlenschleimhaut in chronischen Entzündungen der Kieferhohlen und der Siebbeinzellen ergaben metaplastische Veränderungen der oberflächlichen Epithelialschicht samt verdickten unteren Stützzellen, mitunter Vermehrung der Becherzellen. Das Bindegewebe zeighi stellenweise

schwartige Einziehungen, welche eine Atrophie der einzelnen Komponenten der hyperplastischen Schleimhaut hervorrufen Ringsum atrophisch veranderter Schleimdrusen und Blutgefassen findet man zahlreiche Lymphocyten, Plasmazellen, Eosinophile und Histiocyten In 3% der Falle von allergischer Kieferhohlenentzundungen war verdickte Basilarmembran deutlich geschwollen und mit Eosinophilen infiltriert Benachbarte Knochenwand zeigte osteoporotische Veranderungen, welche haufiger im Bereiche des Siebbeins vorkommen Jede Infektion vergrossert das obige Oedem und fuhrt zur Polypenbildung Verstopfung der Schleimdrüsen mit cystischer Degeneration und schwartige Veranderungen der Blutgefassen Die nachfolgende Atrophie ist verantwortlich fur das kornige Aussehen der betreffender Nebenhohlenschleimhaut

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224 Old Brompton Road, London, S W 5

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EXPERIMENTAL STUDIES ON SOUND TRANSMISSION IN THE HUMAN EAR

H. C. Andersen, C. C. Hansen and E. Neergaard
Aarhus, Denmark

From the Department of Otolaryngology and the Institute of Physics, University of Aarhus

By means of the experimental set up described, in which an automatic sound level recorder is employed, it is possible to obtain a graphic representation of the sound conduction (so called transmission characteristics) in the ear of post mortem human temporal bones.

A decreased transmission of the high frequency range has been obtained by filling the tympanic cavity with water, whereas a reduction of the low frequency transmission occurred as a result of pressure changes in the tympanic cavity.

Finally, it is shown that fenestration of the superior semicircular canal produces a reduction of the response in the low frequency range.

Developments in surgery of deafness have resulted in a wide variety of methods for surgical reconstruction of a more or less adequate sound conducting mechanism in the various forms of conductive deafness. These methods employ implantation of foreign bodies or ossiculoplasty and usually lead to anatomical conditions of the middle ear which deviate markedly from normal.

We have gradually gained a considerable amount of experience as to the effect of these surgical measures, but we have no exact knowledge of their significance in the sound conduction of the ear. Such knowledge can only be obtained through experiments.

The purpose of the experiments reported below was to provide a possibility of measuring the sound transmission through the ear under normal and experimentally produced pathological conditions corresponding to those present in conductive deafness and after surgical intervention aiming at its correction.

In the living subject, normal and pathologically changed sound transmission can be estimated only by threshold audiometry or by impedance measurements on the tympanic membrane.

Numerous investigations on sound transmission have been performed in experimental animals by means of measurements of cochlear potentials. Those interested are referred to Wever & Lawrence: *Physiologic Acoustics* (1954).

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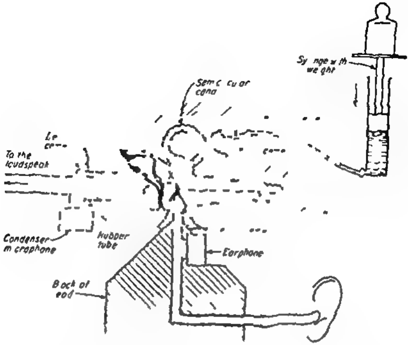

FIG. 1. Diagram showing the arrangement used by von Békésy.

A priori experiments on human ears must be considered to be more appropriate.

von Békésy (1942, 1949, 1960) describes a method by which it is possible post mortem to measure the sound conduction through the ear in temporal bones (Fig. 1). In this method a sound signal is transmitted through the tympanic membrane and middle ear to the intralabyrinthine fluid.

The vibrations which appear at the round window generate a sound wave in a tube cemented to the bone surrounding the membrane. The volume amplitude of the round window is measured by a compensation method in which a tone produced in the opposite phase from an adjusted sound source cancels the signal.

However, the signal is obviously very weak. In order to obtain suitable experimental conditions it may therefore occasionally be desirable to use an input sound level of up to 130 db (ref. 2×10^{-4} dyne per cm²).

A sound pressure of this magnitude must be expected to change the function of sound conduction in the middle ear (cf. von Békésy 1960).

In order to improve the experimental conditions we utilized the *reciprocity theorem*. According to this theorem the transfer of a signal from source to receiver is independent of the interchange of source and receiver. Apart from a few exceptions which are of no importance in this connection the reciprocity theorem may be applied to even very complex sound conducting systems.

When the amplitudes in the middle ear must be kept within physiological limits the sound pressure at the source may be considerably higher when the

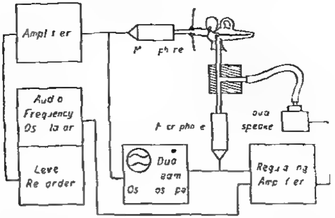

FIG. 2. Diagram showing the arrangement used in the present experiments.

sound is applied to the round window and transmitted to the external auditory canal than if the opposite direction of transmission is used, because an appreciable attenuation occurs in the transfer through the round window. In our experiments the sound was therefore applied to the round window, and the signal which had passed through the transmission system was measured in the external auditory canal. We used a sound pressure which measured in a microphone amounted to 126 db (ref. 2×10^{-4} dyne per cm²).

The measurement of the signal in the external auditory canal may be made either by the aforementioned compensation method or, more easily, by a very sensitive measuring microphone. The signal may then be recorded on an oscillograph and be measured for each frequency separately. The measurements are facilitated considerably by the use of an automatic sound level recorder.

By means of such an experimental set up (Fig. 2) it is possible to obtain a continuous curve for the output signal at all frequencies from 100 to 6000 cps in about half a minute. In the accompanying graphs the basis line corresponds to a microphone voltage of 0.16 millivolt, and the dynamic range of recording is 50 db.[1]

Such a curve will hereafter be referred to as the transmission characteristic of the anatomical specimen concerned. It must be noted that the form of the curve is not determined exclusively by the sound conducting properties of the specimen; the tube connection for the microphones also adds certain details to its shape.

The paths of the curves vary somewhat from specimen to specimen, and the variations greatly exceed what might be ascribed to differences in the connection between the measuring instruments and the specimen. This must be taken as evidence of variations in the sound transmission under normal conditions from specimen to specimen.

By the experimental set up used it is thus not possible to obtain accurate

[1] Microphone sensitivity 3.18 millivolts/μbar.

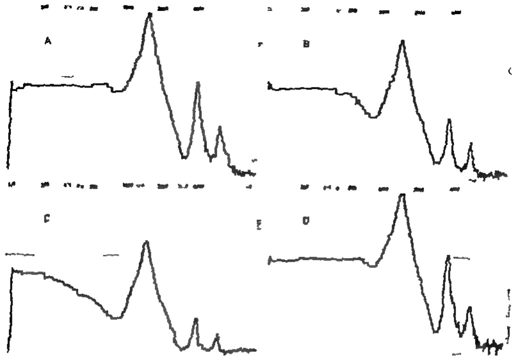

Fig 3 Transmission characteristics A under normal conditions B C after closing the external meatus with cotton plugs of different size D after removal of the cotton plug

absolute figures for the transmission but any change referable to intervention in the sound path will be reflected in the curve by a physiologically relevant magnitude

In addition to the aforementioned transmission characteristic the set up gives a possibility of continuous recording of variations in the signal (at a constant frequency) during the progress of some procedure e g continued changes in the pressure in the middle ear Variations in the sound transmission at the frequency concerned under variable conditions may be read directly from the curve

Preparation of the Temporal Bone Specimens

So far we have prepared 30 temporal bones by the method described below *In most cases the specimens were used the same day as they were* removed at autopsy but a few specimens were stored in airtight containers at 4 C for 24 hours The latter specimens proved to be just as suitable for our experiments as those used immediately after removal

In locating the round window we used a method described by von Bekesy (1942) A hole was drilled through the floor of the tympanic cavity and a probe was inserted into the facial canal in order to indicate the direction of *the drill hole von Bekesy stated that the hole should* be drilled 6 mm medially and anteriorly to the stylomastoid foramen However this statement proved to hold only in about one half of our cases and therefore we used an

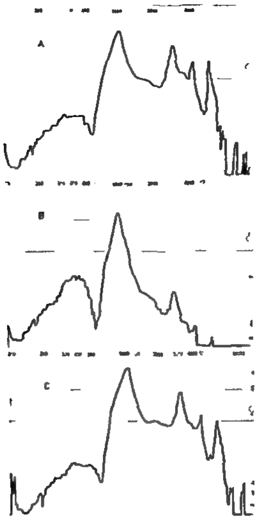

Fig. 4. Transmission characteristics. A, under normal conditions. B, after filling the tympanic cavity with water. C, after removal of the water.

intense light source in the external auditory canal as a guide in locating the tympanic cavity.

A tube with an internal diameter of 1.7 mm and 30 mm in length was fixed to the bone around the round window by means of Harward phosphate cement. The drill hole was closed with a quick drying acryl mass. In some cases the specimen had to be discarded because the round window could not be found or appeared to have the shape of a slit.

In order to ensure a sound proof and airtight connection to the round window, the tube was provided with a connecting branch for a manometer. By creating a positive or negative pressure in the tympanic cavity any leakage in the cement could be revealed. By opening the tympanic cavity it can be shown if the connection is sound proof. If the connection is not sound proof a con-

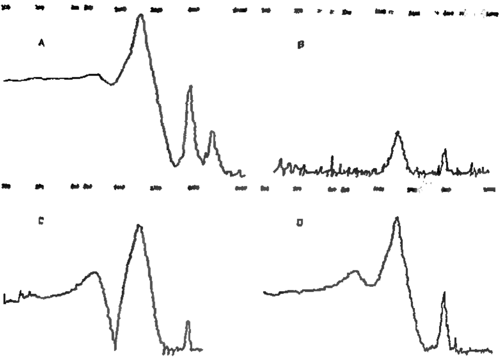

Fig. 5. Transmission characteristics. A: under normal conditions. B: after removal of the incus. C–D: after re-implantation of the incus as a columella between the stapes and tympanic membrane.

siderable change occurs in the sound transmission when the cavity is opened, while this is not the case when the connection is sound proof.

It might be objected that the sound conducting mechanism might be affected by post mortem changes in the temporal bone.

Drying up must be assumed to be of significance. However, no drying up occurs until the temporal bone has been removed from the body and the middle ear has been opened. If the mucosa of the middle ear is moistened and the opening closed again, there is no risk of drying up during the experimental period. As regards other post mortem changes it may be mentioned that von Bekesy stored temporal bones in a lysol solution at 5°C for a fortnight, and showed that the sound conducting properties were completely unchanged.

Another objection is that the normal intralabyrinthine pressure is changed post mortem, and that this change may exert an influence on the characteristic. However, measurements performed by von Bekesy and by ourselves have shown that the intralabyrinthine pressure does not influence the characteristic. Nothing happens until the membrane of the round window is ruptured.

Accordingly, we find that it is justified to claim that the temporal bones used in the experiments had exactly the same sound conducting properties as the ear in a living subject.

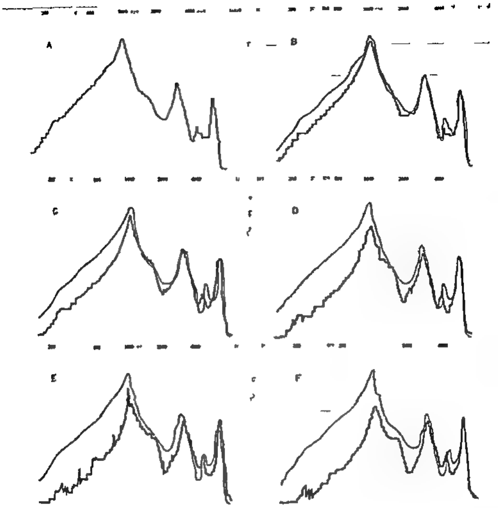

Fig. [illegible] Transmission characteristics. A, at normal air pressure in the tympanic cavity; B–F, at negative pressures: B, 10 cm H_2O; C, [illegible] cm; D, 3[illegible] cm; E, [illegible] cm; F, [illegible]5 cm.

Another question is if the signal which we measure in the external auditory canal has actually passed through the labyrinth and the middle ear or if it has followed some other sound path.

The following observations show that the signal actually passes through the sound conducting system, i.e. through the labyrinth and the ossicular chain.

1. If the tube is cemented to some other place in the middle ear instead of to the round window, no signal can be detected in the external auditory canal.

2. The signal changes as soon as any of the components of the system is interfered with. A change in the signal is observed if the auditory canal is plugged with cotton, if the tympanic membrane is perforated, if the ossicular chain is interrupted, or if the labyrinth is opened and the intralabyrinthine fluid is allowed to escape. If the interference is reversible, the signal returns to normal as soon as normal conditions have been restored.

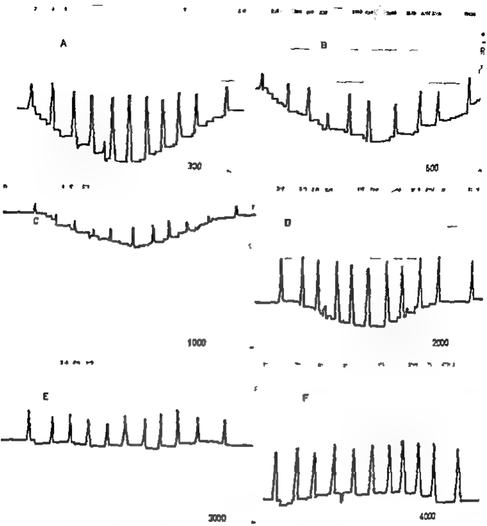

Fig 7 Continuous recording of the amplitude in the external meatus during pressure changes in the tympanic cavity (from normal to 50 cm H_2O and back to normal) The peaks indicate pressure differences of 10 cm of H_2O *A*, *B*, *C* *D* *E* and *F* show six different frequencies

These phenomena were demonstrated in a series of experiments, the results of which are graphically represented in Figs 3–8

If the external meatus is plugged with a tuft of cotton (Fig 3), the transmission characteristic changes with decreasing response in the high frequency range After removal of the cotton plug the response regains its normal size

Similar changes with decreasing response in the high frequency range occur when the middle ear is filled with water (Fig 4) but also in this case the response returns to normal when the middle ear is emptied On interruption of the ossicular chain (removal of the incus) the response disappears completely (Fig 5) When the incus is re implanted as a columella between the stapes and tympanic membrane, the response is regenerated and may

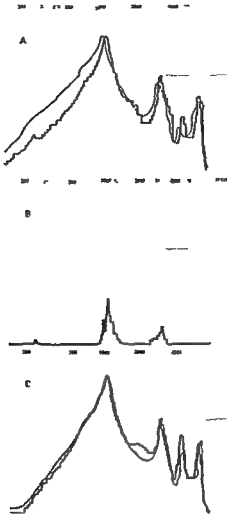

Fig. 8. Transmission characteristics. A, before (thin line) and after (thick line) fenestration of the superior semicircular canal. B, after suction of intralabyrinthine fluid. C, after refilling the labyrinth with saline (thick line). The thin curve indicates the characteristics at A (after fenestration).

become almost perfectly normal, provided the incus is placed in a suitable position (Fig. 5 *D*).

Changes in the pressure in the middle ear result in hearing loss. When a negative pressure was produced in the middle ear of the temporal bones studied, the transmission characteristic showed a considerable change (Fig. 6). On increasing negative pressure a decreasing response to low frequency signals was observed, while the response to high frequencies remained almost unchanged. At −30 cm H_2O in the middle ear, even a slight increase in the response at 4000 cps was observed (Fig. 7).

As the sound path, in addition to the middle ear, also includes the labyrinth, it must be expected that changes in the labyrinth will also influence

the transmission characteristics. As shown in Fig. 8, a change occurs when the superior semicircular canal is opened, evidenced by a reduced response in the low frequency range, while the transmission of high frequency sounds is unchanged. When the intralabyrinthine fluid is sucked out (Fig. 8B) the signal disappears entirely, but complete regeneration is observed when the labyrinth is filled with saline.

On the basis of these observations we find that the experimental set up used in this study is suitable for measurements of the sound transmission in the ear of post mortem temporal bones, and that the results obtained may be applied to the conditions *in vivo*.

ZUSAMMENFASSUNG

Man berichtet über eine Versuchsaufstellung, die mittels eines Schall-Pegel-Schreibers automatisch eine graphische Herstellung der Schalleitungsverhältnisse (ein sogenannter Leitungscharakteristik) im Ohre der postmortal exstirpierten menschlichen Schläfenbeine gibt.

Eine ermässigte Leitung im Diskantgebiet ist dadurch erhalten worden, dass die Paukenhöhle mit Wasser gefüllt wurde, während Druckänderungen in der Paukenhöhle eine Ermässigung der Niederfrequenzleitung hervorriefen. Schliesslich stellt es sich heraus, dass die Fenestrierung des oberen Bogengangs eine Ermässigung der Leitung der tiefen Frequenzen hervorruft.

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Dept. of Otolaryngology
The University of Aarhus
Denmark

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MASKING IN AUDIOMETRY

III. Reflections upon the present position

TAUNO PALVA and ANTTI PALVA
Turku, Finland

From the Department of Otolaryngology, University of Turku

The rules governing the use of masking in air and bone conduction audiometry are discussed and the situations leading to cross hearing are presented. The advantages and disadvantages of the bone conduction masking procedure (Rainville) are considered. The authors at present prefer a frontal placement of the bone conduction receiver, the masking noise being led to the ear by an ear canal insert. The latter increases the interaural attenuation by 15 to 20 db and thus facilitates bone conduction audiometry.

Elimination of any chance participation of the opposite ear in tests for hearing is an ever important question in audiometry. With good technique, reliable audiograms can be recorded even in difficult cases, and they are an invaluable tool for the clinician in estimating the proper direction of treatment. On the other hand, faulty technique may lead to serious errors, the curves obtained may actually be shadow audiograms from the non-tested ear.

One may often find in audiologic laboratories that the rules governing the various testing procedures are not logical and allow loopholes for misleading results. Our intention in this paper is to discuss some of these sources of error as well as to examine some of the new techniques proposed for more accurate tests for bone conduction thresholds.

Air Conduction Tests

The testing personnel, on being asked, usually state that they follow the rule of masking the better ear if the difference between the ears exceeds 40 db. The rule is based on the fact that when testing an ear with unilateral deafness, the sounds are heard by the normal ear with an average of 50 db loss across the head. This being so, a difference of 40 db should safeguard against false curves.

The amount of interaural attenuation can most conveniently be tested in cases of unilateral deafness. Fig. 1 shows the curves of eight such cases, the loss across the head varies from 40 to 65 db with an average of 50 db loss.

As stated earlier (Palva 1954, 1958), this rule is not correct: the difference

from the normal should be the decisive factor not the difference between the ears In cases of sensorineural deafness it is true the above rule would give reliable air conduction curves However as soon as a conductive component steps in values obtained would in many cases be misleading and incorrect air conduction audiograms would result In addition to an example given earlier (Palva 1958) another rather convincing case may be cited

We had a case with a large perforation in both tympanic membranes and were planning some tympanoplastic procedure for alleviation of deafness The better ear showed a 30 db hearing level by the ordinary non masked air conduction test and since this was a pure middle ear lesion bone conduction was normal

The other ear had become totally deaf some years ago due to labyrinthitis Testing the air conduction in this deaf ear without masking the good ear showed a hearing loss of about 50 db e g the curve was depressed by the amount of interaural attenuation Clearly this result if unsuspected would have led the clinician to an unnecessary operation which furthermore would have failed to give any hearing improvement

Seeing that the curve obtained from the poorer ear was depressed below the 40 db hearing level the use of 70 db effective masking (re normal) in the good ear allowed proper air conduction testing in the poorer ear and the result showed it to be totally deaf thus it was possible to make the tympanoplasty in the functioning ear

The first in fact the only rule to be followed in air conduction testing is therefore masking in the better ear is indicated whenever the poorer ear is depressed below the 40 db level

The type of noise suitable for masking has also been discussed earlier Let it be stated once more that proper masking can be obtained either with broad spectrum white noise or with narrow band noise When using white noise the level of effective noise need seldom exceed 50 db in cases of sensorineural deafness In conductive lesions some of the masking power is lost through the conductive component and therefore it may be necessary to employ an effective level of 70 to 80 db (re normal) The simple Rinne tuning fork test should be routinely performed by every audiologist for better pre orientation It does not matter if the test is false negative due to the lack of masking in the latter ear a negative Rinne as such should put the audiometrician on his guard against pitfalls in air (and bone) conduction audiometry

Bone Conduction Tests

The possible sources of error in bone conduction audiometry have been extensively discussed earlier by the senior author (1954 1958) In addition to ordinary methods tests have also been made with various types of ear canal insert receiver leading the masking noise into the non tested ear As stated earlier by Littler *et al* (1952) Zwislocki (1953) and Hood (1957) interaural attenuation can be raised by this means from 80 to 100 db however the

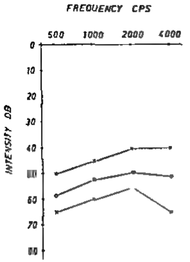

FIG. 1

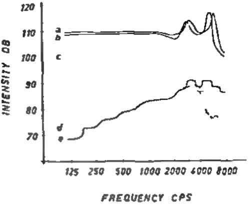

FIG. 2

FIG. 1. Interaural insulation in eight cases of unilateral deafness measured with an ordinary earphone (33 cm² surface area). The middle curve shows the average loss through the skull at various frequencies. The curves with crosses represent the largest and smallest values measured at each frequency. The zero line refers to the thresholds of the opposite normal ear.

FIG. 2. Technical characteristics of the testing apparatus. Curves *a* and *b* represent the frequency response of the two Beltone TDH 39 earphones to a fixed 0.1 V input, measured with a 6 cc coupler. Curves *d* and *e* show the white noise frequency analyses for a 100 db SPL noise, curve *d* being that of the insert, curve *e* of the receiver. Finally, curve *c* shows the frequency response for the insert with a fixed input of 30 mV, measured with a 2 cc coupler.

maximum figure obtained in our laboratory in optimum conditions was 70 db with a hearing aid type insert.

Since that time we have continued the studies of masking in bone conduction audiometry. After a long search we now use an insert with flat frequency response characteristics. It can be directly fitted to the ear canal without any plastic connecting tubes, in which the development of standing waves was thought to constitute a possible source of error. The surface in contact with the ear canal is still small, about 2 cm², while the ordinary receiver in a Beltone audiometer has a surface of 33 cm².

During the last few years the insert type masking earphone has not been in routine use. The reason for this is that with later models the interaural attenuation has generally been less than 70 db, and we have felt that the time is not yet ripe for abandoning the conventional methods.

It is the purpose of this paper to report the general conclusions we have reached lately. As earlier, the masking method has mainly been used in determination of the interaural attenuation. In addition to this, however, we have also tested some cases of total unilateral deafness, because in these patients the results can be considered superior to any other method for measuring the loss through the skull.

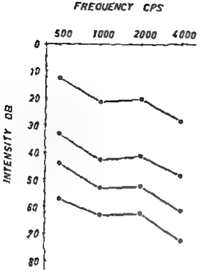

Fig 3

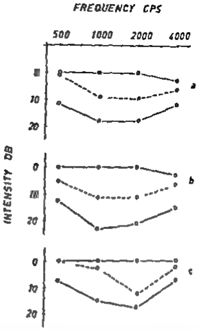

Fig 4

Fig 3 Masking audiograms in normal subjects (noise and tones in the same ear), measured with the TDH 39 earphone Noise levels of 60, 80 90 and 100 db SPL (re 0 0002 dynes/cm²) were used The threshold shifts correspond to the changes in noise intensity Increased masking at the high end is due to the high frequency emphasis in the noise, and to the fact that the zero line refers to normal thresholds (NBS standard)

Fig 4 Contralateral masking Figures *a* and *b* are results in normal ears with 90 db (*a*) and 100 db (*b*) SPL noise in the opposite ear Figure *c* shows the same testing with a 100 db SPL noise in unilateral deafness, the noise being led to the deaf ear The solid lines (noise in the earphone) show clearly more contralateral masking than indicated by the broken lines (noise in the insert) The zero line shows the average unmasked thresholds of the test ear

Characteristics of the Testing Apparatus and Results

The hearing aid type insert, fitted directly to the ear, has now a flat frequency response spectrum from 100 to 4000 cps showing a rather abrupt 15 db loss at 5000 cps (Fig 2) The measurements for bone conduction were made only between 500 and 4000 cps disregarding the lower frequencies, which are somewhat difficult to test with some ambient noise in the testing room

The testing was usually done with a Beltone 15 A model audiometer with TDH 39 earphones showing flat frequency response at a fixed input of 0 1 V between 20 and 7000 cps (Fig 2) The masking noise was of the white noise type controlled in 5 db steps, with a maximum over all intensity of 100 db (re 0 0002 microbar) This noise had a straight frequency spectrum between 1000 and 4000 cps and a gradual loss of 15 db from 1000 to 100 cps (Fig 2)

Fig 3 shows the average masking results in repeated tests on two highly

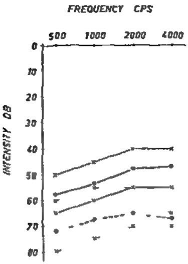

Fig. 5. Comparative data for interaural insulation in unilateral deafness obtained with the tones in the earphone (continuous lines) and in the insert (dotted lines). The average curves for four subjects (open circles) show that insulation using the insert is 15–20 db better than using the earphone. The curves with crosses demonstrate the smallest and largest values obtained at each frequency by the two methods. The zero line refers to the threshold in the opposite normal ear.

experienced persons with the air conducted pure tones and the masking noise in the same receiver. The zero line represents the pure tone thresholds in quiet. It is seen that with increasing masking intensity the masking for pure tones increases proportionately; and owing to the somewhat uneven noise spectrum the masking is least at 500 and largest at 4000 cps.

Another testing arrangement was then used: 90 or 100 db noise in one ear with either the ordinary earphone or the insert, the threshold shift being recorded from the opposite ear. Fig. 4 shows that when the masking noise is introduced via the receiver (solid line) the contralateral masking is clearly greater than when using the insert (broken line). However, the difference between the curves is generally 10 and 15 db and does not reach the 20 db figure reported earlier (Palva, 1958).

The same testing situation was repeated in two listeners with one totally deaf and one normal ear. With 100 db noise the results in Fig. 4*c* are roughly similar to those in Fig. 4*b* with somewhat less contralateral masking than in the normally hearing listeners. The latter may be due to the psychological effect of the noise, its loudness being less marked when it is delivered to the deaf ear.

The final proof of the difference between the ordinary receivers and the insert type can obviously be best obtained from unilateral deaf cases. The results in four such cases are shown in Fig. 5. It is clear that the insert is the better of the two. As an average it gives a 15 to 20 db higher insulation than the ordinary receiver.

New Procedures

In recent years there has been some development away from conventional bone conduction audiometry in an effort to avoid the difficulties due mainly to cross hearing. The greatest interest has been aroused by the method proposed by Rainville (1955) in which the masking noise is led via both air and bone conduction, the difference in threshold from the normal indicating the bone conduction threshold.

The procedure of Rainville has been simplified by Lightfoot (1960); a similar procedure has also been used by Jerger & Tillman (1960) and Hess & Milburn (1961). In this modified Rainville testing the air conduction threshold for pulsed tone is measured first, then a bone conduction vibrator is placed on the forehead and the amount of noise needed to mask the air conducted pulse in the ear is measured. The difference from the normal reference masking level gives the amount of bone conduction loss. In cases of normal bone conduction the intensity masking the pulsed tone in a normal ear and in a conductively impaired ear is the same.

It is claimed that this type of testing eliminates cross hearing and that there is then no need to worry about masking in bone conduction. This is true only if the tests are limited to cases in which the air conduction losses do not exceed 40 db; in cases with poorer hearing the Rainville procedure is bound to lead to faulty results in many cases of conduction and sensorineural deafness, the error will be greater in cases with large differences in hearing levels between the ears.

As already stated, the 40 db limit arises naturally from the fact that the interaural attenuation is almost always greater than 40 db (cf. Fig. 1). In these moderate hearing losses any tone led to the ear by air conduction at 40 db level or less will be heard in that ear only, regardless of the status of the other ear. Consequently the threshold in noise led through bone conduction is affected by the condition of the sensorineural apparatus; the conductive cases show masking levels comparable with normal and sensorineural patients need more masking than normal. The exact amount depends upon the degree of the bone conduction impairment.

However, if the air conduction loss is 50 db or greater, the procedure is no longer reliable. Providing that the other ear is normal or shows pure conduction deafness, all air conducted tones are heard by the contralateral ear when using a level of about 50 db in the test ear, even though the latter ear might be totally deaf. If the bone conducted noise is then put on, the masked threshold from the tested ear will represent values from the non-tested ear and the examiner records a nearly normal bone conduction. The result would thus be entirely misleading.

This difficulty might be avoided to some extent by adding an extra masking noise into the air conduction receiver on the non-tested ear, but this would mean following the paths ordinarily employed in bone conduction audiometry.

The above facts emerge from a purely theoretical study of the Rainville procedure However we have wanted to put on record some results obtained in clinical cases and clearly illustrating the points discussed above It should be stated that in all these cases previous audiometric tests had been made with the conventional technique using masking as indicated earlier (Palva 1954 1958)

Many cases of unilateral deafness were tested the results were uniform and therefore one of them will be presented in detail giving precise figures For greater convenience the results for only one frequency will be reported viz 4000 cps

In this patient the hearing level at 4000 cps in the right normal ear was 5 db and the shadow level obtained with an ordinary receiver on the deaf ear 55 db The clearly heard pulsed tone (+5 db re threshold) in the normal ear was made to disappear by a noise level of 65 db The pulsed tone heard from the receiver on the deaf ear was made to disappear by a 70 db noise this would correspond to a bone conducted threshold of about 10 db (Lightfoot 1960) though the patient in fact does not hear at all with this ear

In the second case the left ear was normal and there was a 70 db mixed deafness with perforation on the tympanic membrane on the right side The 4000 cps threshold in the left ear was 0 db while the non masked shadow level in the right ear was 55 db The real bone conduction in the poorer ear was 30 db The pulsed tone from the left normal ear disappeared with a 65 db noise The pulsed tone from the right ear was made to disappear by a 70 db noise this would mean a bone conducted threshold of 10 db which is in effect 20 db better than measured by the conventional methods

The third case had a 10 db hearing level in the left normal ear and a 70 db level in the right ear with typical sensorineural deafness The unmasked threshold for the right ear was 55 db the masked bone conduction level 65 db In the left ear the pulsed (+5 db) threshold tone was made to disappear with a 70 db noise The pulsed tone heard from the right ear was made to disappear with 90 db noise This would mean a bone conduction threshold of 30 db while the actual figure was 65 db

The drawbacks of the modified Rainville procedure are readily recognizable in these cases It leads to wrong results in all those cases in which the pulsed tone delivered at the poorer ear is heard as shadow tone in the contralateral ear the supposed values for bone conduction represent values from the better ear

It has been stated already that in cases with a 40 db hearing level or better the Rainville test always gives correct data and in these cases there really is no need to worry about masking In the case of unilateral hearing levels exceeding 60 db the unsuitability of the method is equally obvious The area between 45 to 60 db is somewhat uncertain depending upon the interaural insulation the values may be quite correct (interaural insulation is large) or they may represent values from the good ear (interaural insulation is small)

It should also be pointed out that the modified Rainville procedure is suitable in all cases of bilateral sensorineural deafness regardless of hearing level: the only requirement is that the difference between the ears does not exceed 40 db. The procedure can be utilized also in mixed deafness provided that the difference between bone conduction in the better ear and air conduction in the poorer ear does not exceed 40 db.

If, using 256 and 512 cps tuning forks, the Rinne test is positive, the audiometrician can employ the modified Rainville method within the limits stated above. In all cases showing a hearing level of 40 db or better the procedure can also be used with confidence. In unilateral deafness exceeding 60 db *the procedure always gives wrong results*. In cases with 40 to 60 db unilateral hearing levels the correctness of the data depends upon the interaural attenuation in each case.

Present Position

Suggestions for the reliable use of masking have lately been reported besides in studies published from this clinic, by Hood (1959), Lidén *et al.* (1959), Lightfoot (1960), Hart & Naunton (1961) and by Feldman (1961). The suggestions differ somewhat depending upon the type of noise and upon the position and size of the receivers.

The conventional method of placing the receiver on the mastoid bone has been used by most investigators although this is associated with well known disadvantages. However, in studying the reliability of repeated tests by this method the figures by Carhart & Hayes (1949) and by Palva & Ojala (1955) have shown the mastoid route to be good for clinical purposes.

Placing of the vibrator on the forehead ensures good contact with the bone and both ears can be tested without changing the position of the receiver. *The values from the forehead are some 5 to 10 db lower than from the mastoid*, and a corresponding adjustment to normal data should be made.

It is commonly agreed that white noise is the only type to be used in masking. A modification is to use only narrow bands centring the frequency under test. While there is no objection to the latter method, we have hitherto been satisfied with white noise. The unnecessary loudness questioned by Hood is not generally harmful, as high levels of masking are needed only in bilateral conduction deafness and in these cases the conductive component itself reduces the loudness.

As discussed above, the (modified) Rainville technique can be used only in cases with mild to moderate hearing levels in which the masking difficulties *are negligible even with conventional methods*. We are therefore not convinced of the advisability of replacing the old methods with this technique which cannot be used with confidence in all cases.

One requirement accepted by most authors is to have the ear under test open and *not covered by the earphone in the bone conduction tests*. Meatal occlusion would render the bone conduction values somewhat better than

they actually are in normal cases and in cases of sensorineural deafness. If the stapes is fixed, the meatal air conduction factor would be negligible. In a Rainville type of test, covering of the ears would not affect the result materially; it would tend to depress slightly the bone conduction values in normal ears and in sensorineural deafness, whereas good bone conduction in conduction deafness would not be altered.

Having the tested ear open, however, causes some alterations in the results depending upon the ambient noise level in testing room. This affects in the main the low frequencies 125 and 250 cps. Between 500 and 4000 cps data remain reliable even in normal or near normal ears and the reference levels are thus directly related to impaired values. In addition, the 250 cps tone carries no extra information that could not be obtained from the 500 cps tone.

Our present practice is to employ the frontal route, the receiver being fixed on the center of the forehead with an adjustable elastic band. It is attempted to keep the pressure equal in all cases although no measuring of the pressure is made. The insert is always used for masking in the ear canal if these are of normal size. In operated cavities the old fashioned receiver is preferred.

It seems that the interaural insulation provided by the insert cannot be considered to increase the usual 50 db figure by quite as much as 20 db; the true figure with the present apparatus is between 15 and 20 db (cf. Fig. 5). The rules governing reliable masking would not be materially altered from those presented earlier (Palva, 1958). Some points, however, should be emphasized again.

As seen in Fig. 4a, we can deliver a 60 db effective noise into the normal ear without substantially altering the threshold of the test ear when insert masking is used. In normal contralateral ears, and in cases of perception deafness therefore, the masking levels in the masked ear are always known and reliable (cf. Fig. 3) and no difficulties are encountered.

In bone conduction deafness of milder degree the masking is quite simple because the effective level of noise in the ear remains sufficient for reliable masking without depressing the threshold in the test ear. The same applies to unilateral conduction deafness. Great caution is needed, and errors are most easily committed in cases with bilateral conduction deafness of equal degree, about 50 db.

If, using an insert, the effective noise level of 70 db (re normal) is reduced by the conduction deafness to 20 db, bone conduction values better than 20 db would be true and represent the ear being tested. If they fall below the 20 db level, they may come from the contralateral ear. To decide the point one must use another masking level which will show whether there is any change in the thresholds.

We should like to cite still another case tested recently, in which the difficulties are well illustrated. This was a patient with bilateral extensive otosclerosis upon whom several bilateral stapes mobilizations had been done. The last test showed a 40 db hearing level in the better ear, with an air

conduction curve of 70 db in the poorer ear. Only 60 db of effective masking (re normal) had been employed in the better ear for testing the poorer side.

The result seemed suspicious because the testing arrangement would give an effective level of about 20 db in the better ear due to the conduction component; the tones heard at 70 db in the poorer ear would, through the loss of 50 db across the skull, be heard at a 20 db level by the normal bone conduction of the better side. *This proved to be the case: increase of masking revealed* the poorer ear to be deaf. In speech tests this was also clearly confirmed, the score being 0 %.

In testing bone conduction, the better ear showed normal values. In the poorer ear, the bone conduction values correlated with the effective noise level in the masked ear, increasing with increased masking levels. Thus the testing procedure here was similar to the "shadowing" procedure of Hood and there appeared no change-over point. *In the Rainville test this deaf ear* gave bone conduction threshold close to normal.

We wish to stress once again the great value of speech tests in all doubtful cases of conduction deafness. If masked curves show good intelligibility, the air and bone conduction thresholds are likely to be reliable; if speech thresholds and intelligibility scores are out of relation to the pure tone curves the latter are likely to be shadow curves. The speech signal is so much more complicated than the pure tones that weaker and even insufficient noise can prevent shadow speech hearing.

ZUSAMMENFASSUNG

Es werden die den Gebrauch von Maskierung in der Luft- und Knochenleitungs-Audiometrie bedingenden Regeln erörtert und die zum Kreuzhören führenden Umstände dargestellt. Die Vor- und Nachzüge des Knochenleitungsmaskierungs-Verfahrens (Rainville) werden erwogen. Gegenwärtig bevorzugen die Verfasser eine frontale Placierung des Knochenleitungs-Empfängers, wobei das Maskierungs-geräusch vermittels eines Ohrengangseinsatzes ins Ohr geleitet wird, welches das interaurale Schwinden (Attenuation) mit 15–20 db erhöht und somit die Knochenleitungs-Audiometrie erleichtert.

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Kaskenkatu 4 b
Turku Finland

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ELECTRICAL ACOUSTICAL RESPONSE TO CLICK STIMULATION AFTER SECTION OF THE EIGHTH NERVE

Ugo P. Fisch[1] and Robert J. Ruben
Baltimore, Maryland, U.S.A.

From the Department of Otolaryngology, The Johns Hopkins University School of Medicine, Baltimore, Maryland

The source of the neural components of the electrical response to a click at the round window is investigated in cats.

A method of severing the eighth nerve while leaving the blood supply to the cochlea intact is described.

Both components of the neural response to click, the N_1 and N_2, are still recorded at the round window after section of the eighth nerve.

The latency of N_1 and N_2 is not significantly changed after section of the eighth nerve.

A new slow negative potential appears in the electric response to a click at the round window after section of the eighth nerve.

An increase of the amplitude of the action potentials recorded on the peripheral end of the eighth nerve is observed following section of the nerve.

INTRODUCTION

The electrical response to a click recorded at the round window membrane in the cat and other animals has been shown to have several components. Two main types of phenomena are recorded from the round window when a click of a short duration is presented. The first in time is called the cochlear potential which is thought to be derived from the non neural transducer elements of the cochlea. This is characterized by a direct representation of the sound waves which activate the ear. This phenomenon was first noted by Wever & Bray in 1930.

The other electrical phenomena which are observed at the round window in response to a click stimulus are slow waves. Two spikes, called N_1 and N_2, are generally visible. They are in no way related to the configuration of the sound wave impinging upon the ear and are thought to originate in the neural elements which are within the cochlea. This portion of the phenomena observed at the round window was first described in detail by Derbyshire & Davis in 1935.

The neural and non neural components of the round window phenomena

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[1] Research fellow in Oto physiology of the Department of Otolaryngology, The Johns Hopkins Hospital. Permanent address: Clinic of Oto-rhino-laryngology, Zurich University, Switzerland.

differ in various ways. The neural portion, the N_1 and N_2, follows the cochlear potential after a small delay, usually about 0.6 msec (Derbyshire & Davis 1935). The non-neural component replicates the sound stimulus (Derbyshire & Davis 1935). The cochlear potential will change with the polarity of the stimulus but the N_1 and N_2 will not (Derbyshire & Davis 1935). After the death of the animal the neural component will disappear much more rapidly than the non-neural cochlear potential (Derbyshire & Davis 1935, Wever *et al.* 1941). The amplitude of N_1 and N_2 can be changed by stimulating the efferent fibers to the cochlea in the olivo-cochlear bundle (Rasmussen 1946, Galambos 1956, Ruben & Sekula 1960).

The assignment of the N_1 and N_2 to the neural elements of the cochlea still leaves the question as to which of the neural elements within the cochlea gives rise to these phenomena. The N_1 is thought by some to arise from the activity of spiral ganglion cells (Kahana *et al.* 1950, Sorensen 1959). Others feel that it originates central to the ganglion cells, in the nerve fibers in the modiolus (Tasaki 1954). The N_2 was thought to be related to either the cochlear nucleus in the brain stem (Kahana *et al.* 1950, Sorensen 1959, Katsuki & Davis 1954) or to the repetitive discharge of the fibers in the modiolus (Tasaki 1954).

The present study attempts to find out which of the neural phenomena observed at the round window come from central sources and which originate in the cochlea itself.

Electrodes were placed on the eighth nerve and on the round window. Clicks were used to stimulate the ear. Recordings were made before and after section of the eighth nerve, and after elimination of the cochlear blood supply.

METHOD

Animal preparation

Seven adult cats weighing from 2.4 to 3.5 kg were used. Intraperitoneal nembutal 30 mg/kg was given initially. Additive doses of 15 mg of nembutal per kg were given as needed. A heating pad was used to keep the animal's rectal temperature at about 38°C. The bulla was exposed and opened. In all cases the middle ear was free from infection. Through a posterior craniotomy approach, the cerebellum was exposed and gently suctioned away until the eighth nerve was clearly seen. At this point, an electrode was placed on the distal end of the eighth nerve as it entered the internal auditory meatus (position *B* in Fig. 1) and another electrode was placed about 2–3 mm central to the first one (position *C* in Fig. 1). Control recordings were then made. The nerve sheet was incised and the nerve tissue was carefully suctioned away without disturbing the blood supply. During this procedure, the electrode in position *B* was left in place. At all times, the suction tip and the eighth nerve were carefully observed through the dissecting microscope. After section of the nerve, the electrode in position *C*, which was temporarily removed, was returned to its former location. The same stimulus parameters

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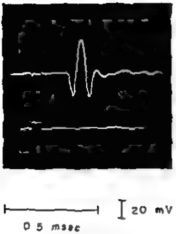

Fig 2

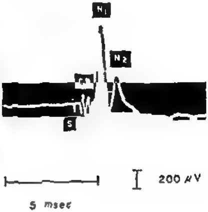

Fig 3

Fig 2 *Upper trace* Click recorded with the Western Electric Type 640-AA condenser microphone three inches away from the speaker Duration of the microphone response 0 2 msec *Bottom trace* 0 007 msec square wave used to initiate the click

Fig 3 Response at the round window to a click of 30 db S stimulus artefact *CP* cochlear *potential* N_1 N_2 neural components

to 1000 cps was used This was connected to a Tektronix type 532 cathode ray oscilloscope A Grass Model C4A camera was employed for recording

The experiments were conducted in a shielded sound proof room

RESULTS

Response to click before section of the eighth nerve

The cochlear potential recorded at the round window in response to click appeared after a delay of 0 4 msec (Fig 3) It consisted of two and a half cycles of a sinusodal wave (Fig 3) The frequency of the first cycle of the

Table 1 *Change of the latency of the action potentials recorded at the round window and at the eighth nerve when the sound stimulation was increased from 40 db to 0 db*

	N_1		N_2		R_1	
	L_f msec	L_p msec	L_f msec	L_p msec	L_f msec	L_p msec
40 db	1 05	1 45	1 88	2 25	1 61	2 14
0 db	0 82	1 08	1 54	1 90	1 27	1 82
Difference	0 23	0 37	0 34	0 35	0 34	0 32

N_1 N_2 = action potentials observed at the round window membrane (electrode position A Fig 1) R_1 = action potentials observed at the eighth nerve first negative deflection at electrode position B (Fig 1) The latency was measured to the foot (L_f) and to the peak (L_p) of each wave

Fig. 1. Horizontal section through the temporal bone of the cat (× 12). *A* is the electrode position at the round window, *B* and *C* are the electrode positions on the eighth nerve. The dotted line shows the area in which the nerve was suctioned away. *n.f.* = nervus facialis. *n.a.p.* = nervus ampullaris posterior.

were used again over a 24 hour period. In some of the animals, the blood supply was cut at the end of the experiment. The animal was perfused with 10 % formalin at the conclusion of the experiment and the temporal bones were saved for histological study. The temporal bones were decalcified, imbedded in celloidin, and sectioned to 24 μ. Staining was done with Ehrlich's hematoxylin and eosin. Every tenth section was mounted.

Instrumentation

Clicks were generated from 0.07 msec square waves through an LS 3 Isophone Electrostatic Speaker (Fig. 2). The interval between clicks was 2.5 sec. The speaker was placed three inches from the external auditory meatus of the cat. The intensity of the click was attenuated in 10 db steps from a maximum value of 50 V across the terminals of the speaker (=0 db). The threshold value of N_1 and N_2 was reached at approximately 40 db below reference level. The configuration of the click used, as reproduced by a Western Electric Type 640 AA condenser microphone placed three inches from the speaker, was equivalent to one and a half cycle of a wave of 7100 cps (Fig. 2). The round window response to this click was such that the cochlear potential ended before the N_1 began (Fig. 3). This made possible accurate measurement of the latency of N_1 and N_2.

Electrodes were made from a No. 26 gauge stainless steel wire, insulated with a thin coat of teflon. The electrodes used in the eighth nerve were pointed. The electrode used on the round window membrane had a ball tip of about 1 mm in diameter.

A Tektronix type 122 low level preamplifier with a band pass of 0.8 cps

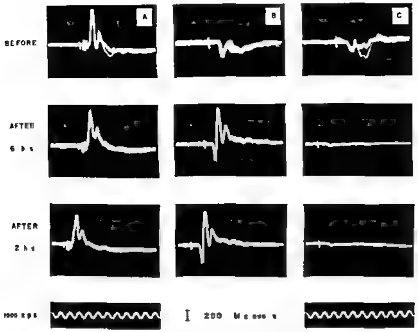

Fig. 5. Cat 231. A, B, C refer to the position of the electrodes (see Fig. 1). Each frame consists of thirty superimposed consecutive tracings. *Upper line*: electrical response after section of the eighth nerve with the blood supply remaining intact. Intensity of the sound stimulation 20 db.

intensity from −40 db to 0 db produced a change of 0.23 msec in the latency of the foot of N_1, whereas the change in the latency of the peak of N_1 was of 0.37 msec. The same increment of the sound stimulation caused a decrease of the latency of the foot of N_2 of 0.34 msec and a decrease of 0.35 msec for the latency of the peak of N_2 (Table 1).

At electrode position *B* on the eighth nerve (Fig. 1) the response to the click was a positive deflection followed by one or more negative deflections depending upon the intensity of the stimulation (Figs. 4, 6). The latency of the first negative deflection was 1.6 msec. This latency was shortened by an increase of the intensity of the sound stimulation. The decrease in latency was approximately the same as that observed for N_1 and N_2 (Table 1).

The amplitude of the action potentials at the eight nerve was always less than one third of the amplitude of N_1.

At point *C* (Fig. 1) an initial positive deflection followed by several small negative deflections appeared in response to the click stimulation (Figs. 4, 6).

Whereas the responses at positions *A* and *B* (Fig. 1) were found to be consistent in all the animals, a greater variability was observed at point *C*.

Response to click after section of the eighth nerve with the blood supply remaining intact

The cochlear potential recorded at the round window following section of the eighth nerve remained constant for the next 24 hours.

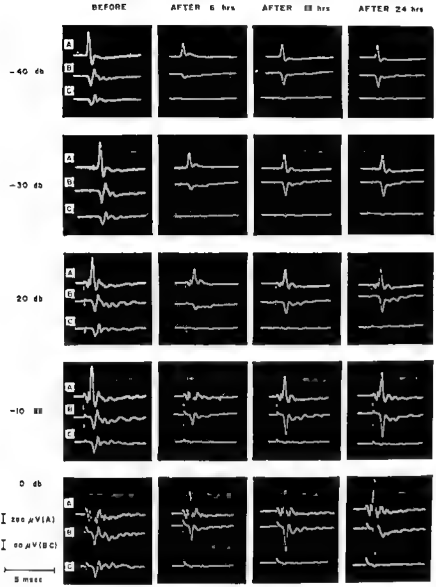

FIG. 6. Cat 236. *A, B, C* refer to the position of the electrodes (see Fig. 1). The electrical responses before and up to 24 hours after section of the eighth nerve are shown for the different sound intensities used.

Both components of the neural response, N_1 and N_2, were still present following section of the eighth nerve (Figs. 4–6). After section and for 24 hours, the latency of N_1 and N_2 showed no significant change from the control measurements (Fig. 7).

The following changes were noted in response at the round window and at the auditory nerve.

1. At the round window a slow negative potential appeared after the onset of N_1, displacing the foot of N_2. This potential was at maximum amplitude

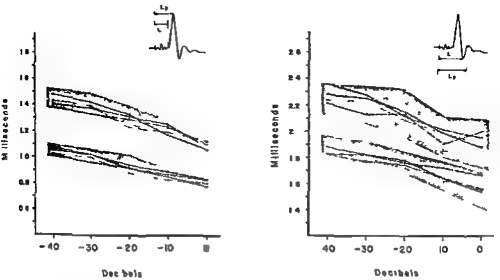

FIG 7 Cats 135 231 232 233 234 235 and 236 Measurements of the latency of N_1 and N_2 before and up to 24 hours after section of the eighth nerve The latencies were measured from the stimulus to the foot (L_f) and to the peak (L_p) of N_1 and N_2 The measurements of the latency of N_1 are shown on the left and those of N_2 on the right

At each intensity level the dots represent the means of the latencies of N_1 and N_2 from 1 24 hours after section of the eighth nerve The ——— line connects the mean latency of N_1 and N_2 one hour after section (mean of seven animals) The line connects the mean latency of N_1 and N_2 six hours after section (mean of seven animals) The line connects the mean latency of N_1 and N_2 12 hours after section (mean of seven animals) The — line connects the mean latency of N_1 and N_2 24 hours after section (mean of four animals)

The grey area indicates the 95 % confidence limits of the mean latency of N_1 and N_2 before section The confidence limits were calculated with the student t test using the following formula

$$x + t \frac{s}{\sqrt{n}} \qquad (1)$$

The standard errors of the mean latency before and after section did not differ more than 10 % for each intensity level s in formula (1) was therefore calculated for each intensity as mean of all the standard errors before and after section

immediately after section of the nerve and subsequently diminished in size but was still present 24 hours later (Figs 4 6)

The new slow negative potential was more evident at a low intensity of sound stimulation (Fig 6)

2 There was a reduction in the amplitude of the normal response at the round window Twelve hours following section of the auditory nerve the amplitude of N_1 was reduced to 60 85 % and the amplitude of N_2 to 35 55 % of the control value (Fig 8) No further reduction was observed in the next 12 hours

3 There was an increase in the amplitude of the action potentials at the electrode position B (Figs 4 6) The maximum values of the increment in amplitude occurred after several hours following the section of the eighth nerve This increment was more marked at high intensities of stimulation

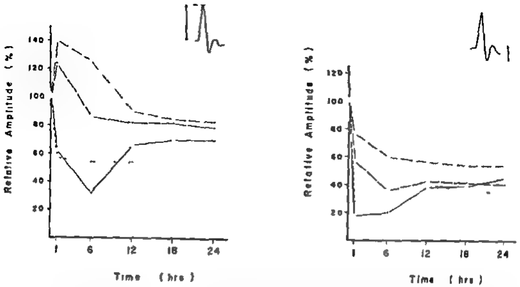

FIG 8 Cats 195, 232 235 and 236 Measurements of the relative amplitudes of N_1 and N_2 after section of the eighth nerve The amplitude of the response before section was taken as 100% value ———, cat 195 ——, cat 232 – – – –, cat 236 — — —, cat 235 The intensity of the sound stimulation was −30 db However similar results were obtained with all the click intensities used

4 In four of the seven animals, the configuration of the action potentials recorded at electrode position *B* became biphasic after the section of the eighth nerve (Figs 4, 5)

5 In two of the seven animals, the latency of the first negative deflection of the action potentials recorded on the eighth nerve at the point *B* (Fig 1) was reduced to 0 2 msec In the others five no change in latency was noted

6 At the central portion of the eighth nerve (electrode position *C* Fig 1) there was no response to a click stimulus following the section of the auditory nerve (Figs 4–6)

Response to click after section of the blood supply

The neural components disappeared in approximately one minute after the blood supply was severed The cochlear potential showed a marked reduction immediately after section of the blood supply and was barely visible 10 minutes later (Fig 4)

Histology

Examination of the serial sections in each animal revealed that in all cases each nerve was sectioned distal to the cochlear nucleus Only an occasional ganglion cell could be seen in three of the seven animals

DISCUSSION

The N_1 and N_2 were still present in the cochlear response to a click after section of the eighth nerve with preservation of the blood supply to the organ

of Corti and the neural structures in the modiolus Therefore the origin of both the N_1 and N_2 must be distal to the section It appears that N_2 does not come from the cochlear nucleus of the brain stem

Changes in the latency of N_1 and N_2 might be effected by efferent fibers running in the eighth nerve No significant change in the latency of N_1 and N_2 was found after section of the eighth nerve This finding would suggest that efferent fibers do not affect the latency of N_1 and N_2 It is of interest to note that stimulation of a known group of efferents the olivo cochlear bundle appears to affect only the amplitude of N_1 and N_2 (Galambos 1956 Ruben & Sekula 1960)

The changes observed in the cochlear response to click at the round window after interruption of the continuity of the auditory nerve i e reduction in amplitude of the neural response and appearance of a new slow negative potential may be a possible consequence of the injury to the nerve or may be the effect of losing the central efferents The immediate appearance of the new slow negative potential at the round window after section and its subsequent gradual reduction would suggest that this phenomenon was associated with an injury potential

The increase in amplitude of the response of the eighth nerve at the electrode position *B* can likewise be attributed to the injury potential of the nerve or to the lack of the efferent fibers The observation that the increase in amplitude of the action potentials was at maximum only several hours after section tends to suggest that this phenomenon might be brought about from loss of the central efferents

ZUSAMMENFASSUNG

Nach einem akustischen Klick Signal wird am runden Fenster der Katze die elektrische Aktivitat abgeleitet und der Ursprung ihrer beiden nervosen Komponenten (N_1 N_2) untersucht Eine Methode zur Durchtrennung des achten Nerven unter Schonung der Blutversorgung zu Cochlea wird beschrieben

Auch nach Durchtrennung des achten Nerven konnten die beiden Komponenten N_1 und N_2 der nervosen Aktivitat nach Klick am runden Fenster abgeleitet werden Die Latenz von N_1 und N_2 zeigt keine wesentliche Veranderung nach Durchtrennung des achten Nerven Nach Durchtrennung des achten Nerven erscheint ein neues langsames negatives Potential in der elektrischen Aktivitat die nach Klick am runden Fenster abgeleitet wird Nach Durchtrennung des achten Nerven wird an dessen peripherem Stumpf ein Amplitudenanstieg der Aktionsstrome beobachtet

Bei der beschriebenen Methode werden efferenten Fasern im achten Nerv mit durchtrennt Der mogliche Einfluss dieser Lasion auf die am runden Fenster abgeleiteten Potentiale wird besprochen

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Dept. of Otolaryngology, The Johns Hopkins University School of Medicine, Baltimore, Maryland, U.S.A.

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REORIENTATION AND VESTIBULAR FUNCTION

A comparison in the human centrifuge between fighter pilots and non aviators

ULF BRANDT
Stockholm, Sweden

From the Medical Unit of the Royal Swedish Air Force and the Laboratory of Aviation Medicine (Head Ass Prof H Bjurstedt), Karolinska Institutet, Faculty of Medicine, Stockholm

Determinations of oculogravic illusion at increasing rotation speeds of the centrifuge, in accordance with a technique previously described

Results of the two test groups are almost identical, in seeming contradiction to what has been shown of the habituation tendencies of the vestibular apparatus Author suggests a psycho physiological explanation to account for this

Among the conclusions oculogravic illusion *in the normal human* is suggested to indicate the effect of linear acceleration on the inner ear provided this stimulus remains within reasonable limits For stronger linear stimuli the phenomenon is believed to be an expression of a combined otolith proprio exteroceptive excitation

INTRODUCTION

The basis of reorientation without the aid of visual references is no doubt to be found in a stimulation of peripheral sense organs by mechanical stimuli, among the sense organs in question the inner ear seems to play a role which, even if not decisive is of the greatest importance This opinion is strongly supported both by rational arguments and by observations previously published The position of the head therefore and the various angles of incidence of the resultant to the sagittal plane of the test subject in centrifugal tests implies such a variety of reorientation performances that it would almost seem proper to consider the entire function as located in the inner ear In addition, it has been proved that no reorientation of the type mentioned will occur, provided the incident resultant hits the blind spot of the macular planes (Quix, 1925) and that reorientation will occur in the best and most accurate way if this resultant is allowed to act in a craniocaudal direction following a longitudinal plane through the test subject, as on the centrifuge when the subject is sitting upright in a free swinging gondola In the latter case he will always set his subjective horizon at exactly right angles to the resultant without hesitation and delay Despite these observations there is of course no sufficient evidence so far to prove that the sensorial basis of

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spatial orientation without visual aids should be located in the vestibular organ, there being no possibility of differentiating its receptors for linear accelerative stimuli from other receptors for the same type of stimulus (exteroceptors, muscular and articular sensibility, etc.). This has been further stressed by creating the "g receptor" concept, a term coined to cover the vestibular and all other position indicating senses with the exception of vision.

So far, the experiments described have concerned only human test subjects, and the author has from the beginning been quite aware of the objections that may be raised against physiological conclusions founded on perceptions. When trying to assess the validity of these conclusions one has always to keep in mind a factor extremely difficult to define, i.e. the effect exerted by the "higher senses"[1], in other words the "computation" of incoming sensorial information after cerebral integration before the subject produces the result, i.e. reports his conception of his orientation in space. Spatial orientation, as is well known, belongs to the most complicated psycho-physiological functions of man, *acquired from birth onwards and presupposing a subtle co-operation*, still unknown in many intermediary stages, between peripheral sensory impulses and consciousness.

Purpose of the present investigation

The results obtained by a great number of investigators (Cawthorne, Fitzgerald & Hallpike 1942; Hallpike, Harrison & Slater 1951; Aschan 1954; Kruger 1954; Van Egmond, Groen & Jongkees 1952; Hallpike & Hood 1952; Preber 1958) place the experienced pilot, like the figure skater (MacCabe 1960), in a unique position as regards his vestibular functions. The better his flying trim the more the fighter pilot knows how to disregard *the impulses from his position indicating receptors more or less consciously*. By applying eliminating mechanisms (located peripherally according to Hallpike & Hood and Van Egmond, Groen & Jongkees, acting centrally according to Aschan (1954) and others) he manages to suppress the often very intense labyrinthine stimuli, the same as would cause neurovegetative disturbances, such as nausea ("air sickness"), in subjects without training in aviation. Because of this supposed "unique vestibular position" it has been considered theoretically important and also of a definite practical interest to compare the function of reorientation under similar conditions in trained pilots and in a material of controls without flying experience.

MATERIAL

The groups of pilots and controls each comprised 10 subjects, all of them without any neurological or other pathological data in their records. No injuries of the brain

[1] Various experiments suggest that a central process is concerned. Hamberger and Hydén's (1949) experimental cytochemical investigations appear to support this interpretation.

and skull no motion sickness or other sign of functional vestibular disturbances could be traced in any of the subjects With regard to the age of each individual the two groups were selected to provide about the same average although the controls were on the whole somewhat younger The records of all the pilots showed comparatively uniform and uneventful flying histories in the case of the oldest aviator extending over 12 years All the pilots had a least 800 flying hours to their credit, the majority more than 1200 flying hours of all round practice in the most modern jet planes In addition they all showed records of vestibular illusion misinterpretation of the position etc phenomena that were considered normal and easy to remedy and belonging to normal aviation routine Nothing had been said about these illusions at the annual medical examinations

METHOD AND APPARATUS

As for the centrifuge the measuring apparatus and the recording system the reader is referred to previous publications by the author

Summarizing the general conditions one gets the following picture

The test subject is sitting in an *exactly vertical* position his trunk and head steadily fixed to the horizontal centrifuge platform facing in the direction of motion and having the axis of rotation of the centrifuge on his left The setting of the horizon is carried out as stated using a slightly illuminated indicator at a normal reading distance in front of him in complete darkness Hence the indicator is rotated by the subject at the various stages of the experiment to coincide completely with his current conception of the horizontal By reading the angular difference in the control room between the horizon at stationary conditions (non moving centrifuge) and the perceived fictitious horizon at a certain step of rotation of the centrifuge one obtains an exact measure both of the oculogravic illusion and of the reorientation in accordance with the active resultant of forces In reality the horizon at stationary conditions coincided with very small deviations with the gravitational horizontal and hence it was possible prior to each test to set the recording indicator in the control room according to the markings made by the test subject

The tests were made as follows The centrifuge stationary at first was accelerated *very slowly* to the nearest stage of rotational speed These stages had been fixed at 0 2 4 6 8 10 12 and 14 r p m At each stage the test subject was instructed to set his horizon 10 or 12 times Prior to every marking the preceding marking was recorded then off set following a system common to all the test series

Besides the markings by the test subject the control room at each stage received the angle of deflection of the phimeter a damped pendulum indicating the direction of the resultant of the radial and gravitational accelerations The test subject being kept all the time in a strictly vertical position the direction of the resultant corresponded to the angle of incidence of the contact force at each speed stage to the test subject s sagittal plane (cf Fig 1 p 10? *Acta Ot laryng Suppl 140* (1958))

Every test series was divided into consecutive accelerating and decelerating stages As has already been mentioned the rotational speed changes of the centrifuge between stages occurred very slowly Thus the angular acceleration (and deceleration) could scarcely have exceeded 0 2 sec sec² at any time It was therefore considered permissible to neglect the effect of angular and also tangential acceleration and deceleration respectively No importance was attached to the time required by the

test subject of form his estimate and do a marking The value stated as final by the subject was recorded

For practical reasons the calculations of the results were based on the *difference* ($\Delta\Phi$) between the angle indicated and the phimeter reading At markings greater than the phimeter reading the angle value was considered positive (marked +) and in the contrary case negative (−) Complete coincidence was marked thus ±0

CHARACTERISTICS OF THE PHYSICAL STIMULATION

At each rotational speed the test subject is acted upon by a force—always directed outwards—which is the vector sum of all forces present (centrifugal force gravitation and at rapid changes of the rotational speed additional forces causing tangential and angular acceleration respectively) Owing to the careful fixation of the test subject these forces are transmitted to him by the particular outfit (such as chair straps and bit) employed to hold him in the determined position Although there is a certain damping effect owing to the properties of the material e g the straps and the yield of the body tissues the physical stimulation is affected mainly by an inertial or con tact force the direction of which is opposed to that of the resultant

At very slow changes in the rotation speed meaning that on the whole tangential and angular accelerations may be neglected the stimulation is consequently caused by the non progressive linear acceleration following from the combination of centrifugal and gravitational acceleration This acceleration is characterized both by its direction and its magnitude The direction is indicated by the angle Φ between the resultant and the direction of gravity Its exact value at the various stages of rotation is known from the phimeter or by simple calculation

The magnitude of the active stimulus can be established according to the formula

$$\text{Tot Acc} = g_0 \sec \Phi\,(^1)$$

or in *G* units

$$\text{Tot Acc} = \sec \Phi$$

These values at various rotation speeds are summarized in the middle section of Table 1 the variations in Tot Acc in Fig 1

RESULTS

As could be expected the dispersion of the 10–12 measurements on each test subject at each stage of rotation speed was comparatively great within both groups Although there were several subjects both among the pilots and the controls who did not hesitate to give a definite value and stick to it at very small variations the relative dispersion characterizing the sizes of the angles as stated by others caused the writer to choose the *median* as the representative value since in a material of this kind the median has tradi tionally been considered the typical value

[1] $g_0 = 981\ 8$ cm sec

TABLE 1 *Oculogravic illusion as a function of rotation speed Comparison between pilot material and controls*

Values based on *difference* between angle stated by test subject and ph meter reading Variations in direction of vector resultant in relation to sagittal plane of test subject (Φ) compared to Tot Acc

r p m	Pilots		Angle Φ	Tot Acc (in G)	Control	
	Mean	S D			Mean	S D
0	0	0 25	0	1 00	+ 2 4	1 6
[illegible]	—	—	1°8	1 0004	—	—
4	+ 2 5	1 3	8°	1 0079	− 1 9	2 2
6	− 4 4	5 5	17°	1 0367	4 6	1 75
8	− 2 4	2 8	28°	1 105	+ 0 1	5 4
10	+ 5 6	2 0	39°	1 222	+ 6 1	8 1
12	+ 10 1	3 5	50	1 414	+ 11 2	4 6
14	+ 15 7	4 9	60	1 880	+ 13 7	4 2
12	+ 10 7	3 3			+ 7 4	5 1
10	+ 4 3	1 8			+ 1 8	2 1
8	+ 0 6	7 5			0 4	7 1
6	0 8	5 9			2 1	3 4
4	+ 4 3	4 2			+ 1 1	2 82
2	—	—			—	—
0	+ 0 9	0 30			+ 4 1	2 89

The treatment of the data appears in Table 1 Fig 2 offers a graphical representation of the mean of the median as a function of the rotation speed for the pilot and control groups separately and for both groups taken together It is striking to note the almost complete coincidence of the two groups a phenomenon which may be considered the main finding at the present investigation It will be further discussed later on A detailed study of the matter leads to the following picture

At standstills before and in particular after *runs* ΔΦ is + 0 (with a few minor exceptions) This seems to support Graybiel s observation of lacking adaptation (1952) During the phase of acceleration and as far as the 8 r p m stage there is some slight difference between the groups (a certain under estimation of Φ in the pilot group as against ΔΦ = ±0 in the control group) From that stage onwards the pilots have corrected their under estimates whereas the controls are somewhat lower After this both groups stated plain over estimates reaching + 14° on an average at 14 r p m

During the phase of deceleration this over estimation is progressively reduced and reaches ΔΦ = +0 at 8 r p m A slight over estimation is again noticed at 4 r p m but finally disappears when the centrifuge has come to a standstill

There were hence systematic variations in ΔΦ at certain stages of the

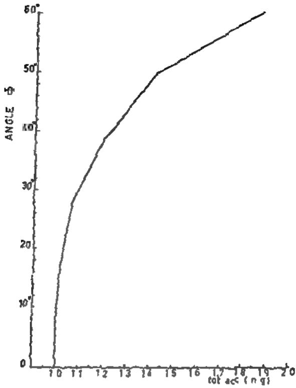

Fig 1 Variations in Total Acceleration (in G units) as a function of Φ

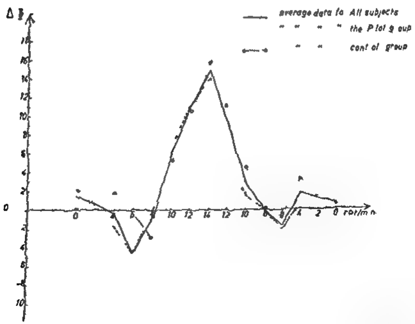

Fig 2 Oculogravic illusion as a function of rotation speed Comparison between pilot material and controls Values based on *difference* between angle stated by test subject and phimeter reading

experiment When rotating at medium speed (6 r p m) there was an under estimation of Φ which in the case of the pilot group averaged 17 per cent Within this group the under estimation is significative When rotating at high speed (12 and 14 r p m) a significative over estimation of 8 and 13 per cent respectively, was found in each group

As regards $\Delta\Phi$ the tendency was the same in both groups and during both phases

DISCUSSION

The results summarized above will be discussed from two aspects Firstly they offer information about the orientation function of the vestibular apparatus and secondly they supply information that is of importance in the practice of flying at zero visibility

The seeming rotation of the indicator as experienced by the test subject (oculogravic illusion) has been interpreted by some workers (Graybiel *et al*) as a direct otolith response to an adequate physical stimulus however the bases of this interpretation are somewhat questionable The angular acceleration on the other hand has been kept at subliminal values in these tests in order to avoid any stimulation of the cupula according to the conventional belief Throughout the entire experiment consequently no sensation of turning or of oculogyral illusion was reported Hence the mechanical stimulation was purged of extraneous influences to form a contact power which for a physical point could be compared to the attractive force of the earth At each stage of rotation speed this vectorial force caused an acceleration (Tot Acc) of a certain relative angle of incidence and of a certain magnitude (always > g_0 however) If Tot Acc were g_0 there would not be much difference between these experiments and a simple tilting of the test subjects in a tilting chair

Table 1 shows however that Tot Acc scarcely exceeding g_0 at rotation speeds up to [illegible] r p m increases rapidly at higher speeds and almost reaches 1 9 G at top speed The relative angle of incidence (Φ) however shows a rather uniform increase about 10 for each stage of rotation speed (Fig 1)

Magnus & Kleyn (1920) and also Quix (1925) asserted that the stimulation mechanism within the maculae was to be found in a positive or negative pressure by the otoconia acting on the sensorial hairs The same opinion has also been held by Werner (1920) and Rademaker (1926) Here one finds a distinct correlation between the increase in Tot Acc and the systematic over estimations This fact may be used in favour of the pressure theory just mentioned and may also provide some support for a direct interdependence between illusion and otolith stimulation

The latter opinion however is contradicted by the results from experiments conducted on patients with an acquired vestibular areflexia that have been published in a previous paper by the same author (1952)

Another interpretation of the curves may also give quite a different picture of the physiological mechanism i e at increasing rotational speeds there is

an increase in *static muscular activity* (proprioceptive sense) along with tangential shifts and differences in load and tone in the various layers of the skin (exteroceptive sense). Knowing the comparatively high minimum perceptible of these senses it would seem possible for perceivable impulses to be released from these sense organs *only at high speeds* (8 and more r.p.m.); the same sense organs would then, at following increase in stimulation intensity, be responsible for the tendency to overshoot.

Although it is obvious that the present investigation does not provide conclusive evidence in favour of either explanation there are reasons to believe that the illusion produced at low or medium speeds of rotation is actually a pure otolith effect, whereas the phenomenon at higher speeds implies a combined otolith–proprioceptive response. This idea is further supported by the results obtained by Walsh (1961) when testing patients immersed in water with high spinal lesions and vestibular damage in his parallel swing device. The investigations by Walsh aimed at a comparison between the threshold values of linear acceleration in these two groups of patient, and from his results he concluded that "sensitivity to linear motion depends primarily on the vestibular apparatus".

It would seem appropriate to comment on the almost complete identity (with a few exceptions) between the curve obtained from the pilot group and that of the controls.

In the same way as considering oculogyral illusion as integration process on a high level and produced by angular acceleration—the view held by many workers (van Dishoeck and others)—it is possible in an analogous way to interpret oculogravic illusion as a central process produced by linear acceleration causing stimulation of *g* receptors. The peculiar phenomenon of "habituation", briefly referred to in the introduction, is found in individuals who have been subjected to frequent stimulation of the labyrinths. Habituation manifests itself chiefly by a reduced response to angular accelerations, whether the effect of stimulation is a turning sensation, oculogyral illusion or nystagmus. Similar results have been obtained in animals (Henriksson 1961).

The information obtained in my investigation, important theoretically and practically as it may be, seems to indicate that *no such effect* can be proved experimentally in the case of *g* receptors. Certainly the seeming contradiction regarding this difference may give rise to speculation. To excite or stimulate implies to interfere with an "equilibrium" and the response by the living organism aims at restoring the equilibrium. This process, which is easier to study at a simpler or more primitive stage of development, may be described in the following terms:

excitation→disturbance of the equilibrium→reaction

or by the sequence

stimulus→excited organism→response

In organisms developed beyond the reflex level where various reactions have been made possible owing to the more advanced properties of the nervous system the stimulus response process is co ordinated with some type of experience

A rotation is *comparatively unusual* in the average human somewhat less unusual among pilots and a commonplace among pirouetting professional dancers Hence it is not surprising when considering our knowledge of the adaptability of other body functions that repeated disturbances of the equilibrium as produced by rotations will eventually lead to a stage of reduced response Also it would seem natural that such inhibition is localized at a high integration level

As for the receptors concerned with linear accelerations they are known to be in a state of continuous and uninterrupted stimulation (in contra distinction to the semicircular canals) It is sufficient to point at the permanent stimulus from gravitational acceleration adaptation to such a fundamental function would scarcely be adequate since every disturbance of the equilibrium has to be recorded immediately to allow an adequate reaction to be set up For the same reason hence oculogravic illusion with its individual variations giving a true image of this function cannot be influenced by adaptation

This conclusion is of great practical interest in flying at zero visibility Where the prerequisites for an illusion are present *the illusion is not reduced by training* but its annoying influence is *generally* of no consequence as concerns the trained pilot s conception of his spatial orientation

ZUSAMMENFASSUNG

Messung der okulograven Illusion bei steigenden Zentrifugengeschwindigkeiten gemass der fruher beschriebenen Technik

Die Resultate sind praktisch identisch in beiden Gruppen was scheinbar in Widerspruch steht mit dem was uber die Habituieringstendenz des Vestibularis bekannt ist Der Versuch einer psychophysiologischen Erklarung dieses Unterschiedes wird gemacht

In den Schlussfolgerungen wird im ubrigen vorgeschlagen dass die okulogravse Illusion *bei normalen Individuen* den Effekt einer linearen Akzeleration auf das Innerohr anzeigt wenn sich diese Reizung innerhalb massiger Grenzen halt Bei hohen linearen Stimuli dagegen durfte das Phenomen Ausdruck fur eine kombinierte otolithische proprio exterozeptive Reizung sein

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Brahegatan 7b, Stockholm Ö

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HEREDITARY MALFORMATIONS OF THE EAR IN THREE GENERATIONS

Marginal Pits Pre auricular Appendages Malformations of the Auricle and Conductive Deafness

L S WILDERVANCK
Groningen, The Netherlands

From the Anthropogenetical Institute of the University and Royal Institute of the Deaf Groningen

A family has been described in which in three generations deformed (flapped) ears pre auricular pits and pre auricular appendages occur Conductive deafness may be an accompanying feature The importance of the knowledge of this syndrome in connection with genetic counselling and detecting deafness at an early stage of life has been stressed

The relation of the malformations mentioned in the title is embryologically understandable The *auricle* is formed by growth of the mesenchymal tissue covered by ectoderm and flanking the first gill furrow In the fifth week (9 mm) on each side i e on the first and second pharyngeal arrow there appear three hillocks which already are fused in an embryo 18 mm long (Streeter 1922 Grimaud & Wasoff 1956) Afterwards the surroundings of the furrow grow out and form the pinna of the ear the far greater part being formed by the second the hyoid arch From the fact that the six tuberculae coalesce which most probably does not always occur in the same way it is not surprising that there exist so many differences in the configuration of the auricles and that it is an exception for two persons to show exactly the same form of auricles Variability of the auricle is already recognizable in very young embryos (Hochstetter 1948) The hillocks most probably do not have a *fundamental* signification in the development of the auricles they have only a transient character (Streeter 1922 Hochstetter 1948) Moreover the hillocks are also formed in reptiles and birds which show no external ears at all!

The *external auditory meatus* is chiefly formed from the ectodermal gill furrow but the manubrium of the malleus develops in close connection with the forming of the outer meatus (Hammar 1902 Goedbloed 1960)

The *ear drum* formed between the bottom of the ectodermal groove and the bottom of the entodermal sinus of the oral cavity which forms the tympanic cavity originates from the same tissue in which the manubrium develops (according to Goedbloed the middle ear (tympanic cavity) is a part of the

oral cavity which is formed after disappearance of the first gill pouch extends itself laterally and is *not* formed from the first pouch itself as we find in most textbooks)

The *malleus* is formed in the first branchial arch the *incus* in the pterygquadrate bar between the first and second arch and the *stapes* is derived from two sources namely the second visceral arch and the lateral labyrinthic capsula wall (Anson & Bast 1946)

The malformations found in the family under discussion are the *following*

Flapped ears abnormally curved auricles an anomaly we may see also in combination with microtia (Hanhart 1949 Goldenhar 1952) Flapped ears are rather common

More severe malformations of the ear accompanied by atresia auris Under development and even absence of the auricle can be explained by irregular or insufficient growth of the margins of the first and second branchial arch especially the second (hyoid) arch Atresia auris arises by non development of the ectodermal groove or the development only of a small ectodermal fistula which does not reach the ear drum As the primary external auditory meatus is first closed by epithelial growth and—in normal circumstances—opens again by disappearance of the epitheloid cells (Hammar 1902 Hochstetter 1948) atresia auris may also be caused by *failing of this secondary process* Often the ear drum is lacking and cases are known in which the development of the ossicles is very bad Atresia auris with absence of malformation of the ear drum and manubrium mallei is understandable as a result of disturbances of the development in the manubrium mallei region (Goedbloed 1960) Malformation of the whole manubrium the incus and the stapes can be understood by the fact that the exogene noxe or —in hereditary cases—the gene may extend its influence much further (Altmann 1933 1949 1950 1955) *According to Altmann (1949)* the inner ear is also involved in one third of the cases Malformation of the ossicles in an otherwise normal auditory organ is rare (Altmann 1951 *b*) The majority of cases of microtia with atresia are sporadic but dominantly hereditary cases have been described as well (Hanhart 1949 Schinz 1941 Schwarz 1938) A third malformation is one or more *pre auricular appendages* They are small in most cases somewhat oblong tumours sometimes there is a piece of cartilage in the centre As in microtia they may occur unilaterally or bilaterally unilaterally being the most common way Sometimes they are continuous with the anterior margin of the auricle but more frequently they lie in front of the auricle free from it at the height of the incisura supratragicus Hereditary cases are rather rare (Brander 1939 Siemens 1921) The mode of heredity in these cases is dominant It is supposed that pre auricular appendages arise directly by excessive growth from the mandibular arch (Congdon) or by abnormal growth of the skin covering the tuberculae of the margin of the first arch (Goldenhar 1952)

The fourth developmental disturbance which is of great importance in the family to be described is *the pre auricular pit* or *fistula* (fistula auris con

genita) already described in 1864 by Heusinger (Germany) and in 1878 by Paget (England). There exists an extensive literature on this subject. The far greater part of the auricular pits is pre-auricular. As in the family examined by the present author other fistulae do not occur, I shall only speak of *pre*-auricular fistulae (pits). According to Congdon et al., about 90% of them may be called "marginal": they are seen on or close to the anterior border of the ascending limb of the helix. These are the pits which play an important part in the family to be described in this paper. Regarding the origin of pre-auricular pits or fistulae we may exclude as a source the entodermal visceral pouch. A fistula has never been seen which has a connection with the cavum tympani; furthermore their walls are microscopically strictly ectodermal and of a cutaneous character (Congdon et al.). Some investigators, e.g. Stannus (1914), think that the fistulae arise from the ectodermal groove *between the two first visceral arches, though a connection between fistula* and meatus acusticus has never been seen. Precechtel (1927) and even Paget (1878) point to the fact that collar fistulae and pre-auricular fistulae may occur together in one individual. As collar fistulae originate from the lower branchial fissures, "so may these aural fistulae be regarded as similarly due to incomplete closure of the first post-oral fissure" (Paget). Another theory is that the pits arise by failure of fusion of the tuberculae on the margin of the mandibular arch (Streeter 1922, Stammers 1927, Whitney 1939, Miller & Moore 1950, Aird 1946). Though it has never been proved, I think, as Aird does, that the least objectionable hypothesis is that of an intertubercular origin.

It is very remarkable that the places of predilection of appendages and pits lie in two curves before the auricles, with the convex side turned to the tragus (Wood Jones & Wen I. Chuan 1934). The appendage line is situated somewhat in front of the pit line. Thus both lines are situated in about the same place—in which we can imagine that the mandibular and hyoid folds grew together (Altmann 1951 *a*). The close relationship between appendages and pits or fistulae in this way seems easily understandable: both developmental aberrations arise from an abnormal growth, perhaps also a shifting of tissue of the first visceral furrow with its surroundings, the first two arches. Pits or fistulae are often described as being hereditary and it would be easy *to collect some 20 cases* in literature. The mode of heredity is dominant here too or sometimes irregularly dominant.

The embryological relation between the formation of middle ear, auricle, pits and appendages being so clear, one would expect that the aberrations mentioned would often occur in one individual, and, as heredity is often obvious, also intrafamilially. Indeed we find descriptions in literature of combinations of two anomalies in one patient, e.g. microtia with pits (Altmann 1951 a, Hanhart 1949), pre-auricular fistulae with appendages on the same auricle (Goldenhar 1952, Vannas 1955). Heusinger (1864) perhaps gives some cases of the same combination (his description is not very clear). Paget (1878) quotes a case of Holmes. Aird writes that occurrence together

Fig. 1. Right: pre-auricular appendage. Left: microtia with atresia auris. Loss of hearing (L) 60 db, (R) only 20 db.

of pits and appendages is "not infrequent", but does not mention any cases. The present author saw a boy, a pupil of a school for hard of hearing children, who had on the left side a severe microtia with a loss of hearing of 60 db along the whole tone range, and on the right side two pre-auricular appendages. The loss of hearing was only 20 db (Fig. 1). Vannas emphasizes the fact that in a patient examined by him the hearing of the ear was fully normal though there were three pre-auricular appendages on this side. Goldenhar mentions a somewhat deformed ear with abnormally curved helix and appendages. Schwarz gives a picture of microtia combined with an appendage and Vannas a typical flapped ear with fistula and appendages. Both patients had aberrations of their eyes. Weaver describes malformations of the auricle and bilateral pre-auricular sinuses. Intrafamilial cases are presumably scarce. Ruttin was able to examine a family in which the mother has a marginal fistula; one of her children had a pre-auricular appendage and two showed a fistula.

It is very remarkable that so few authors mention the *hearing* in their patients with malformations of the auricle, appendages and pits. A boy with conductive deafness was the starting point in the present investigation! Of course, all investigators agree that in cases of microtia with atresia auris there exists deafness, but we find almost no data on hardness of hearing or deafness in cases of appendages and fistulae or pits. Congdon, who was able to investigate a large number of individuals with pits or fistulae, could never verify deafness. We find a vague indication of deafness in patients with fistulae in the publications of Heusinger (1864) and Paget (1878). Vannas mentions a man with malformations of both auricles; in front of them there were appendages and in front of the left auricle there was a fistula as well. According to the audiogram, there existed a slight deafness of a mixed type. This man, however, showed a typical form of *dysostosis mandibulo-facialis*; this is a well defined entity and has no relation with the syndrome of malformation of the auricle, appendages, pits and deafness, which was the subject of the present investigation.

A remarkable family has been described by Fourman & Fourman (1955)

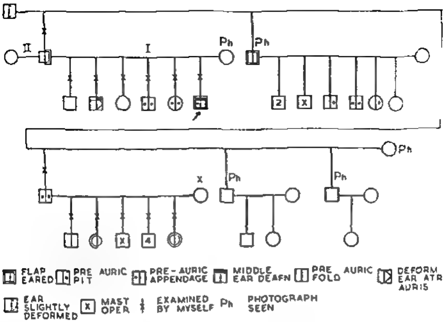

Fig. 2

There existed marginal ear pits or fistulae in three generations in some individuals there were *collar* fistulae and one member of the family had a "collar appendage" Twelve of the members were deaf and three without pits were deaf as well So far as audiograms could be made it appeared to be a *perceptive* deafness (both high and low tones involved but usually the high tones more than the low) This deafness was not congenital, but started at the age of 20 I think this is quite another syndrome

The following is a description of the members of a family I was able to examine (Fig 2)

I, 1 Deceased Right auricle slightly deformed Hearing good (Fig 3)

II, 2 Oldest son of I, 1 (Fig 4) On the left side a flapped ear, the upper part of the helix abnormally curved

Fig. 3 I 1

Fig 4 II, 2

Fig 5 III, 2

II, 4 Second son Flapped ears, hearing good

II, 6 Third son Marginal pits, hearing good By pressing with a finger a badly smelling detritus could be produced

II, 8 Fourth son Normal

II, 10 Youngest son Normal

III, 2 Severe deformation of the left auricle, atresia auris Deaf at this side Marginal pit (Fig 5) Feather in the pit

III, 4 Marginal pits, hearing good

III, 5 Marginal pits, hearing good

III, 6 The probandus, pupil at the School for hard of hearing children in Groningen Flapped ears, low implantation In front of the right tragus an appendage On both sides a conductive deafness (Figs 6 and 7) Presumably the ossicles are deformed (ankylosis?) This is in contradiction with the boy in Fig 1, who has a normal hearing of the appendage ear

III, 8 Mastoid operation on both sides

III, 9 In front of the left auricle an appendage Hears well

III, 10 On both sides a pre auricular appendage Hearing good

III, 11 On the left side a pre auricular appendage Hears well

III, 13 In front of the left ear a fold Hears well

III, 14 On the right side a flapped ear Hears well

III, 15 On one side a mastoid operation Hears well

III, 16 On both sides flapped ears Hears well

Fig 6 III, 6

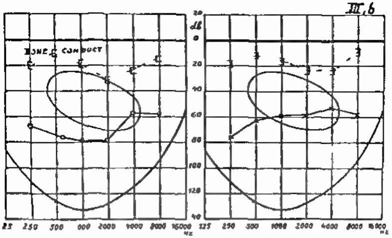

Fig. 7. III 6

The boy III 6[1] excepted, no audiograms could be made. I was obliged to ascertain the hearing in the two families I was able to examine only by hearing whispering and a watch. Using this rather crude method I was unable to detect an impairment of their hearing. The other families gave me extensive written information about their auricles and hearing. I sent them photographs and sketches of microtia, pits and appendages in order to inform them of the aberrations. The connection of the anomalies in this family is evident and a dominant mode of heredity is clear, the expressivity of the syndrome being very variable. Only two members are severely affected: the two sons of II 2; most probably however the flapped ear of the father is "guilty" of their malformations. The father most likely inherited the gene for the syndrome from his father I 1, who had a slightly deformed right ear, his mother being normal.

The two families I visited (the first and third brother, generation II) asked me, of course, about the future progeny of their affected children. If there is a full penetration of the gene — and this seems to be so, as ten children of the three affected brothers show an aberration and eleven are normal, which we may expect in a dominant mode of heredity with full penetration — we are justified in telling the parents that each child of their affected children has a 50% chance of showing the syndrome in a *mild or severe* form. A child severely affected (III 2 and III 6) may get children who show deafness or microtia; it is, however, also possible that they only will show a flapped ear, pit or appendage. The future children of boys and girls who are only slightly affected stand the same chance. These children may show a pit, but a severe conductive deafness is possible too! The fact that the first father (II 2), who only shows one flapped ear, got two children who are severely handicapped makes the latter point clear. But as only two of the 14 abnormal members

[1] The audiogram was made in the Audiological Department of the Ear, Nose and Throat Clinic of the University (Prof. H. C. Huizing).

of the family are severely affected, the chance that they may only show a flapped ear, an appendage or a pit, is much greater. Knowledge of this syndrome seems to me of importance in detecting deafness at an early stage of life in children with often *apparently* unimportant aberrations and in genetic counselling

ZUSAMMENFASSUNG

Der Verfasser beschreibt eine Familie in der in drei Generationen missbildete Ohrenmuscheln, präaurikulare Fisteln und präaurikulare Anhänge gefunden wur den Konduktive Taubheit kann ein Begleitsymptom sein Die Wichtigkeit der Kenntnis dieses Syndroms für genetische Beratung und Aufdeckung von Taubheit bei jungen Kindern wird betont Ausführlich wird der embryologische Zusammenhang der Symptome diskutiert

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Petrus Campersingel 243, Groningen (Holland)

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MALIGNANT TUMOURS OF PARANASAL SINUSES

EINO VAHERI and HEIKKI SETÄLÄ
Helsinki, Finland

From the Department of Otolaryngology (Head: Prof. Urpo Siirala), University of Helsinki

The study is based on 121 cases of tumour treated during the ten year period 1945–54 at the Otolaryngological Clinic in Helsinki. According to site of origin, three groups were distinguished: tumours of the maxillary sinus (80 cases), the maxilloethmoidal region (39), and frontal sinus (2). There were 110 carcinomas (91 %), and 11 sarcomas (9 %). Of the carcinomas, the most frequent type was the spinocellular, and in addition there were anaplastic, basal cell, and adenocarcinomas. All cases were given combined operative and radiation treatment. Electrosurgery was employed in most cases. Instead of ligation of the external carotid artery, temporary compression with an arterial clamp was successfully used in a great number of cases during the operation.

The five-year survival rate was 26 % for the maxillary sinus tumours, [illegible] % for maxilloethmoidal tumours, 27 % for carcinomas, and 18 % for sarcomas.

Malignant tumours of the paranasal sinuses are of interest and importance from the point of view of symptomology, diagnosis, histologic structure and therapy. These neoplasms develop within a bone cavity, which makes them inaccessible to direct inspection. Early diagnosis is therefore difficult, and treatment at the later stages gives poor results in a regrettably large proportion of cases.

It is the purpose of the present study to throw light on the symptomology and the results obtained, taking into account the clinical picture and the histologic appearance. The material includes only primary cases originating in the paranasal sinuses under treatment at the Otolaryngological Clinic of the University of Helsinki during the ten year period 1945–54. Thus in each case five years at least had passed since the commencement of therapy.

The total number of cases was 121, distributed over the different years as follows:

1945	4	1950	12
1946	10	1951	14
1947	8	1952	13
1948	12	1953	21
1949	9	1954	19

A classification according to origin of the tumour and histologic structure resulted in the following groups:

Tumours of maxillary sinus	
Spinocellular carcinoma	53
Anaplastic carcinoma	18
Reticulum cell sarcoma	3
Giant cell sarcoma	[illegible]
Spindle cell sarcoma	[illegible]
Osteosarcoma	1
Unclassified sarcoma	1
Total	80
Tumours of maxilloethmoidal region	
Spinocellular carcinoma	22
Anaplastic carcinoma	6
Basal cell carcinoma	7
Adenocarcinoma	2
Fibrosarcoma	2
Total	39
Tumours of frontal sinus	
Spinocellular carcinoma	[illegible]

The three groups of tumors listed above are all readily distinguishable from one another on the basis of the clinical picture. The designations used indicate at the same time the origin of the tumour. It should be noted, however, that the origin of the maxilloethmoidal tumours was frequently difficult to determine. Evidently some of them were derived from the posteromedial portion of the maxillary sinus and some from the ethmoid cells, while some may also have originated from the mucosa of the middle meatus. Malignant tumours of the maxillary sinus are about twice as frequent as those of the maxilloethmoidal region, and tumours of the frontal sinus are rare.

Carcinomas are much more frequent than sarcomas. In the present study the incidence of the former was 91 %. Spinocellular carcinoma is the most common histological type; it was present in [illegible]7 of our patients, or [illegible] %. The histological picture showed distinct keratinization in 21 cases. The non-keratinized, poorly differentiated types were thus slightly more common than the keratinized, well differentiated types.

Anaplastic, undifferentiated carcinoma was second in order of frequency. It was found in 24 cases, or 20 %, in the maxillary sinus somewhat more often than in the maxilloethmoidal region.

An observation of particular interest was that basal cell carcinomas were only present in the group of maxilloethmoidal tumours. They occurred in seven cases, or 6 % of the total number. Differentiation of basal cell carcinoma from spinocellular carcinoma is usually easy. The epithelium has a tendency to form strands and columns. The cylindrical peripheral cells resemble the basal cells of the oral epithelium. They fail in the normal transformation into squamous cells and show no evidence of keratinization.

In our series there were only two adenocarcinomas, both maxilloethmoidal tumours, representing about 2 %. In Larsson & Mårtensson's (1954) study

too, all adenocarcinomas were localized to the ethmoid or the upper part of the nasal cavity.

There were 11 sarcomas—an incidence of 11 %. Nine of these were tumours of the maxillary sinus and two of the maxilloethmoidal region. In previous studies the incidence of sarcomas has varied considerably. Öhngren (1933) reported 15 %, Ringertz (1938) 5 % and Wille (1947) 6.8 %.

The sarcomas were classified histologically as follows:

Reticulum cell sarcoma	3
Giant cell sarcoma	2
Spindle cell sarcoma	2
Fibrosarcoma	2
Osteosarcoma	1
Unclassified sarcoma	1

Other malignant tumours of the paranasal sinuses have also been reported, such as cylindric cell carcinoma, lymphoepithelioma, malignant melanoma, plasmocytoma, round cell and polymorphous sarcoma, lymphosarcoma, chondrosarcoma, neurosarcoma, myxosarcoma, rhabdomyosarcoma (Saxén 1925, Öhngren 1933, Ringertz 1938, High 1951, Wille 1947, Harrison 1953, Larsson & Mårtensson 1954, Hemenway & Lindsay 1959, Allen 1960).

Tumours of the Maxillary Sinus

This group consisted of 80 patients, 46 male and 34 female. A male preponderance has also been demonstrated in previous studies. It is possible that cigarette smoking plays a part in the etiology of cancer of the maxillary sinus also. The age distribution is given in Table 1.

Table 1 shows that the majority of the carcinoma patients were over 40 years old, the maximum incidence occurring in the age group 50–60 years. The youngest carcinoma patient was 18 years. Sarcoma occurred in younger age groups in particular; in those under 30 years of age it was more frequent than carcinoma. The youngest patient with sarcoma was 15 years.

TABLE 1. *Maxillary sinus tumours: age distribution*

Age, years	Carcinoma	Sarcoma
Under 20	1	3
20–30	0	1
30–40	4	1
40–50	13	0
50–60	27	4
60–70	14	0
Over 70	12	0
Total	71	9

TABLE 2 *Maxillary sinus tumours duration of symptoms*

Duration of symptoms months	Carcinoma	Sarcoma
Under 3	21	1
3–6	31	4
6–12	14	4
Over 12	5	0

The majority of the patients were from rural districts (66 cases) and occupied in manual work (74 cases)

The duration of symptoms prior to diagnosis and admission to hospital varied widely This is apparent from Table 2

Symptoms had been present for a regrettably long time Remarkably often no final diagnosis was established when the patients consulted a physician (33 cases) or dentist (17 cases) at the earlier stage of the disease

The subjective symptoms differed in the different cases and occurred in various combinations Table 3 shows the frequency of the different symptoms at the early stage and later

The most common early symptoms were pain swelling of the cheek and unilateral nasal stenosis and secretion The same symptoms occurred in the later stages accompanied fairly often by ocular symptoms Oral symptoms and blood mixed discharge from the nose were less usual The cases of sarcoma did not differ from those of carcinoma in regard to the incidence of the various symptoms

General health was good in 35 cases poor in one and moderately good in the others Anemia (below 70 %) was present in 31 cases however and marked leucocytosis (over 10 000 cells) in 17 cases The blood sedimentation rate was usually increased in the patients with carcinoma in sarcoma normal values were fairly frequent (Table 4)

The results of physical examination are shown in Table 5

Swelling of the cheek and visible or palpable changes in the oral cavity predominated among the clinical signs Most of the lymph nodes on the neck were metastatic lesions but there were inflammatory lymph nodes in

TABLE 3 *Subjective symptoms in cases of maxillary sinus tumour*

Symptoms	Initial	Late
Pain	46	13
Swelling of cheek	27	19
Nasal stenosis and/or secretion	23	15
Oral symptoms	5	7
Sanguineous discharge	3	[illegible]
Ocular symptoms	1	11

TABLE 4 *Maxillary sinus tumours sedimentation rate*

SR mm	Carcinoma	Sarcoma
Under 10	2	4
10–20	5	3
20–40	28	1
40–60	17	0
60–100	17	1
Over 100	2	0

a few cases The importance of roentgenologic examination is clearly apparent from the fact that bone destruction was present in 67 cases or 84 % It is worth noting however, that bone destruction is not an early sign Since the tumour takes its origin from the mucosa of the maxillary sinus there often appears only a roentgenologic shadow at the early stage The present study includes 13 cases of this kind In some of our cases ordinary roentgen examination was supplemented with roentgen tomography by which destruction of bone was clearly demonstrated

The cases on which this study is based were given a combined surgical and radiological treatment Operation was in most cases performed under intratracheal anesthesia in seven cases local anesthesia alone was used The external carotid artery was ligated immediately before operation in 54 cases In 19 cases ligation was not used the external carotid was exposed and closed temporarily with an arterial clamp The clamp was removed on completion of the operation This compression of the carotid proved to be a very effective and commendable method and ligation was needed in none of these cases Temporary compression of the carotid does not interfere with postoperative circulation and thus recovery can proceed under favourable conditions

The surgical techniques used ranged from the Caldwell Luc operation to complete resection of the maxilla In some of our cases operation also included removal of part of the maxillary skin resection of the zygoma or

TABLE 5 *Maxillary sinus tumours clinical signs on admission*

Clinical signs	No of cases
Swelling or tumour of cheek	[illegible]
Changes in palate or alveolar process	53
Tumour in nasal cavity	17
Tumour in choana	15
Ocular changes	12
Exophthalmus	11
Lymph nodes on the neck	33
Roentgenologic signs of bone destruction	67

TABLE 6. *Maxillary sinus tumours: findings at operation*

Findings at operation	No. of cases
Destruction of bone	
of maxillary sinus wall	71
of palate or/and alveolar process	58
at bottom of orbit	47
Tumour involves	
nasal cavity	38
ethmoid cells	23
orbit	17
sphenoid sinus	3
surface of dura	2
frontal sinus	1

evacuation of the orbit. Electrocoagulation was used in addition for destruction of the tumour and adjacent tissues. Sublabial or other intraoral incisions were made in 43 cases, usually with a diathermy knife. External incision was employed in 37 cases, in most of them by the method of Fergusson, but recently also quite often by Zange's method. Besides a lateral rhinotomy, the Zange approach consists of a horizontal incision splitting the lower eyelid. It gives wide exposure and is extremely favourable from the cosmetic point of view. Lesions suspected to be cervical metastases were removed at the same time.

Operation showed that in most cases the tumour had extended from the maxillary mucosa to the bony walls and very often also beyond the maxillary sinus. Öhngren established a "line of malignancy" running from the inner canthus of the eye to the angle of the mandible, easy to trace in the profile X-ray picture. Tumours situated in front of this line (anteroinferior) are less malignant than those which remain behind it (posterosuperior), for the former may grow much longer before getting into contact with dangerous regions such as blood vessels and meninges. The posterosuperior tumours are in general more difficult to operate upon radically. We found it difficult in most cases to make this classification. The findings at operation are given in Table 6.

These findings show that the range of the indications for operation was fairly wide. Two patients died of operative complications. In one case hemiplegia developed on the day after operation and autopsy revealed an embolism in the internal carotid artery. In the second case there was thrombophlebitis in the leg; the cause of death was not definitely disclosed on autopsy.

Postoperative radiation varied to some extent from case to case: radiation by X-rays in 29 cases, X-rays and teleradium in 18, X-rays and radium in six, teleradium in eight cases, and radium in three cases. Only four patients received preoperative radiation. Palatal defects were corrected in 19 cases by

TABLE 7 *Maxillary sinus tumours recurrences and late metastases*

Lapse of time	Recurrences	Late metastases		
		Neck	Lung	Brain
Less than 3 months	14	3	2	
3–6 months	10	7	1	2
6–12 months	7	3	1	
1–2 years	9	3	1	—
2–3 years	—	—	—	—
3–5 years	3	—	—	—

a suitable dental plate and facial defects in six cases by plastic surgery. Recurrences were treated by re-operation and electrocoagulation.

The time of onset of recurrences following the operation is given in Table 7. More than half of the 43 recurrences developed as early as within six months. The same table also shows the time of appearance and site of late metastases. Lymph-borne metastases to the neck were the most common, but there were also five patients with metastases to the lung and two with brain metastases; the lesions in the pulmonary parenchyma and the brain were evidently metastases by the blood stream. Blood-borne osseous metastases did not occur in the present study. They appear within a relatively short period after surgical or radiation treatment (Motta *et al.* 1961).

When evaluating the results of treatment, those patients were regarded as cured who had remained entirely free of symptoms for five years after operation or after the last recurrence or metastasis. Patients who had died from intercurrent disease during this period of observation were included among those not cured. The five-year results in the group of maxillary sinus tumours were:

Alive after 5 years	21/80	26 %
Alive and symptom-free after 5 years	16/80	20 %

The results vary to some extent in the different groups of tumour. Of the 53 patients with spinocellular carcinoma, 16 (=30 %) were alive after five years and 12 were symptom-free (=23 %). These patients presented changes due to tumour in the bony walls of the maxillary sinus, palate, nasal cavity and at the bottom of the orbit and/or the ethmoid cells, but not in the orbit itself and not on the surface of the dura. Cervical metastases were noted in four cases.

Of the 18 patients in the group of anaplastic carcinoma, four (=22 %) were alive after five years, three being symptom-free (=17 %). Bone destruction occurred in the cured patients in the wall of the maxillary sinus, at the bottom of the orbit and/or the palate; metastases to the neck in one patient.

Only one of the nine patients with sarcoma survived for five years and was

TABLE 8 *Tumours of the maxilloethmoidal region age distribution*

Age, years	Carcinoma	Sarcoma
20–30	2	0
30–40	3	0
40–50	7	1
50–60	6	0
60–70	16	0
Over 70	3	1
Total	37	2

symptom free (=11 %) In this case the tumour had involved the walls of the maxillary sinus, the base of the orbit, and the palate

Thus the best result in the maxillary sinus tumours was obtained in the group of spinocellular carcinoma, the poorest in the cases of sarcoma

Death occurred within 12 months in about 50 % of the cases terminating fatally, and within 24 months in about 75 %

Tumours of the Maxilloethmoidal Region

These patients totalled 39, 19 men and 20 women The distribution according to age is recorded in Table 8

The patients aged 60–70 years were most numerous The majority of patients were from rural districts (31) and occupied in manual work (36 cases)

The duration of symptoms prior to admission to hospital is illustrated in Table 9 The patients in this group came under treatment somewhat later than those with maxillary sinus tumours About half of this number (17) had sought medical aid earlier, but none had consulted a dentist

The subjective symptoms in this group resembled those in maxillary sinus tumours A distinct difference appeared, however, in the frequency of the various symptoms, as seen in Table 10

Nasal stenosis and secretion was the commonest symptom Pain and especially swelling of the cheek, occurred more rarely than in the preceding group Ocular symptoms, however, were remarkably frequent

TABLE 9 *Tumour of the maxilloethmoidal region duration of symptoms*

Duration of symptoms months	Carcinoma	Sarcoma
Less than 3	7	0
3–6	10	1
6–12	8	1
Over 12	12	0

TABLE 10 *Subjective symptoms in cases of maxilloethmoidal tumour*

Symptoms	Initial	Late
Nasal stenosis and/or secretion	25	14
Ocular symptoms	[illegible]	[illegible]
Pain	7	[illegible]
Sanguineous discharge	5	
Swelling of cheek	1	[illegible]
Aural symptoms	—	3
Oral symptoms	—	1

The general condition on admission was good in 13 cases poor in three and moderately good in the others Anemia (hemoglobin below 70 %) was present in 15 cases and leucocytosis (over 10 000 cells) in four The sedimentation rate was under 10 mm in nine patients 10 to 100 mm in the rest thus in most cases increased

Tumour tissue was seen in most cases at anterior rhinoscopy in the upper portion of the nasal cavity and in about half the cases at posterior rhinoscopy in the choanal region (Table 11) Ocular symptoms and swelling of the cheek were also of common occurrence Cervical lymph nodes were present in nine cases, about one quarter of all cases Roentgenological shadows were seen in all cases but there was definite bone destruction in 14 only (36 %) a much lower proportion than in the case of the maxillary tumours

Combined surgical and radiological treatment was used in this group too Ligation of the carotid artery was performed immediately before operation in 13 cases and temporary compression with an arterial clamp in five cases The approach was through an external incision in 22 cases and a transmaxillary approach through a sublabial incision was used in 17 Two patients were treated by plastic operation at a later stage

TABLE 11 *Tumours of the maxilloethmoidal region clinical signs on admission*

Clinical signs	No of cases
Tumour in nasal cavity	33
Tumour in choana	21
Ocular changes	12
Swelling of cheek	10
Exophthalmus	[illegible]
Changes in palate or alveolar process	[illegible]
Lymph nodes on neck	9
Roentgenologic signs of bone destruction	14

TABLE 8 *Tumours of the maxilloethmoidal region age distribution*

Age years	Carcinoma	Sarcoma
20–30	2	0
30–40	3	0
40–50	7	1
50–60	6	0
60–70	16	0
Over 70	3	1
Total	37	[illegible]

symptom free (= 11 %) In this case the tumour had involved the walls of the maxillary sinus the base of the orbit and the palate

Thus the best result in the maxillary sinus tumours was obtained in the group of spinocellular carcinoma the poorest in the cases of sarcoma

Death occurred within 12 months in about 50 % of the cases terminating fatally and within 24 months in about 75 %

Tumours of the Maxilloethmoidal Region

These patients totalled 39 19 men and 20 women The distribution according to age is recorded in Table 8

The patients aged 60 70 years were most numerous The majority of patients were from rural districts (31) and occupied in manual work (30 cases)

The duration of symptoms prior to admission to hospital is illustrated in Table 9 The patients in this group came under treatment somewhat later than those with maxillary sinus tumours About half of this number (17) had sought medical aid earlier but none had consulted a dentist

The subjective symptoms in this group resembled those in maxillary sinus tumours A distinct difference appeared however in the frequency of the various symptoms as seen in Table 10

Nasal stenosis and secretion was the commonest symptom Pain and especially swelling of the cheek occurred more rarely than in the preceding group Ocular symptoms however were remarkably frequent

TABLE 9 *Tumour of the maxilloethmoidal region duration of symptoms*

Duration of symptoms months	Carcinoma	Sarcoma
Less than 3	7	0
3 6	10	1
6 12	8	1
Over 12	12	0

In the group of basal cell carcinomas totalling seven cases two out of seven (29 %) were alive and symptom free after five years One of these showed changes in the maxillary and frontal sinuses besides in the ethmoid cells but neither had metastases to the neck

One of the two cases of adenocarcinoma was a cure in this case the tumour had involved the sphenoid sinus extending to the surface of the dura

One of the two sarcoma cases was also symptom free after five years tumour tissue had been present in the ethmoid region the maxillary sinus and the nasal cavity

The recurrences mostly appeared within 12 months of the start of treatment but in a few cases a recurrence developed as late as after three years Of those who died during the period of observation about 85 % died within 12 months

Tumours of the Frontal Sinus

Malignant tumours of the frontal sinus are rare but there were two in our series a man aged 65 and a woman aged 52 Both of them had had symptoms for less than three months prior to admission in the former case there was nasal obstruction and secretion in the latter swelling of the forehead

The general condition was reasonably good in both cases The sedimentation rate was considerably increased (33 and 104 mm) and roentgen examination showed bone destruction Treatment consisted in operation and X ray radiation The first patient had a recurrence after three years and died one year later the second more severe case terminated fatally within two months of the operation This patient also had cervical lymph node metastases

These two tumours were of spinocellular type the most usual one in the case of frontal sinus carcinomas Mitchell (1960) has recently published one case and reviewed the literature Secondary frontal sinus carcinomas with the site of origin probably in the maxillary or maxilloethmoidal region are much more frequent This material included six such cases one presumably originating in the maxillary sinus and five in the maxilloethmoidal region One of these latter was symptom free after five years (basal cell carcinoma) in the others prognosis was poor

Comments

The cases of malignant tumour of the paranasal sinuses dealt with above were classified by their origin into three groups maxillary sinus maxillo ethmoidal and frontal sinus tumours There were no appreciable difficulties in placing the patients into these groups on the basis of the clinical picture and the findings at operation—not even in those cases in which tumour tissue was present in several of the sinuses The clinical signs showed typical differences Certain special features also marked the histologic structure in the different groups Spinocellular and anaplastic carcinoma were the most

common types while basal cell carcinomas and adenocarcinomas only occurred among the tumours originating in the maxilloethmoidal region

The lymph vessels of the nasal cavity as well as those from the maxillary sinus and ethmoid collect in the choanal plexus The primary regional nodes are the lateral retropharyngeal lymph nodes Metastases to these nodes are difficult to diagnose The secondary nodes are the cranial jugular nodes and metastases to these are palpable in the deep portions of the neck The maxilloethmoidal tumours are situated closer to the regional lymph nodes and therefore usually metastasize earlier than those originating in the maxillary sinus If the former involve the palate the alveolar process or the soft parts of the cheek they can also cause metastases to the submandibular nodes by the lymph vessels running along the anterior facial vein From the zygomatic region and the forehead a carcinoma may metastasize to the preauricular lymph nodes The tumours taking their origin from the maxillary sinus or the maxilloethmoidal region differ further in that the former generally extend more slowly to dangerous areas viz the cranial cavity and the orbit

ZUSAMMENFASSUNG

Die Untersuchung betrifft 121 Tumorfälle, die in der Zehnjahresperiode 1950 1951 in der Otolaryngologischen Klinik in Helsinki behandelt worden sind Der Ausgangsstelle gemäss wurden drei Gruppen unterschieden nämlich Tumoren des Sinus maxillaris (80 Fälle) Tumoren der Maxilloethmoidalgegend (30) und Tumoren des Sinus frontalis (2) In 110 Fällen handelte es sich um Karzinom (91 %) und in 11 Fällen um Sarkom (9 %) Von den Karzinomen war am zahlreichsten der spinozelluläre Typ vertreten und ferner kam anaplastisches Basalzellen und Adenokarzinom vor Alle Fälle hatten kombinierte Operativ und Strahlenbehandlung bekommen Elektrokoagulation wurde in den meisten Fällen angewandt Anstatt einer Ligatur der äusseren Karotis wurde bei vielen Fällen während der Operation mit gutem Erfolg eine Arterienklemme angelegt

Von den Fällen mit Tumoren des Maxillarsinus lebten 26 % über fünf Jahre nach der Operation von den Maxilloethmoidaltumoren 23 % von den Karzinomen 27 % und von den Sarkomen 18 %

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BOOK REVIEW

BALLANTYNE J Chalmers *Deafness* Published by Messrs Churchill London

This book is well worth reading both for the hard of hearing person and for the otologic beginner and as a *repititarium* for the more advanced otologist

The first chapters a good survey of the anatomy as well as the physiology of the ear and a summary of different hearing tests including recruitment and the possibilities of speech audiometry

In the next chapters hearing aids and their limitations are discussed In the following chapters newer otosurgical methods and landmarks are presented with very instructive illustrations This is the case for both tympanoplastic and otosclerosis The following chapters discuss congenital deafness and psychogenic deafness as well as tests of schoolchildren with screening education of the ' hard of hearing child or of the deaf one Many valuable ways and types of schools and training of the child is thoroughly treated

Perceptive deafness malingering and psychogenic deafness are discussed against the background of chances to diagnosis and therapy

In the last chapters the author deals with the handicap of the deaf people and of the hard of hearing man as well as their chances of rehabilitation

The book ends with a good summary and a surveyable index On the whole it can be said that it is a very instructive and stimulating book well worth reading for the patient as well as the advanced otologist and the beginner

C Ahlander

The editor of *Acta Oto-Laryngologica* is hereby authorized to publish the following decision passed by the Collegium O R L A S concerning the publication of their proceedings

All papers read at meetings of the Collegium O R L A S will be published in *Acta Oto-Laryngologica* which will send the proceedings to all honorary members and members The Collegium will pay £250 for the publication of the proceedings of one meeting

Manuscripts should be handed to the secretary at the meeting and should be of about the same length as when read at the meeting The number of illustrations accompanying one paper should preferably not exceed five or one per printed page Any extra cost incurred for illustrations in colour will be charged to the author There will be no reprints free of charge their cost being payable by the author

All members of the Collegium are recommended to subscribe to *Acta Oto-Laryngologica* either personally or through their institutions

L B W Jongkees

Le rédacteur des *Acta Oto Laryngologica* est autorisé par la presente a publier la décision suivante du Collegium O R L A S au sujet de la publication des comptes rendus de ses travaux

Tous les rapports lus aux séances du Collegium O R L A S seront publiés dans les *Acta Oto-Laryngologica* et les comptes rendus seront envoyés à tous les membres honoraires et a tous les membres Le Collegium payera une somme de 250 livres sterling pour la publication des travaux d une séance

Les manuscrits doivent être remis au secrétaire pendant la seance et ils doivent avoir approximativement la longueur du rapport lu à la séance Le nombre des illustrations qui accompagnent un rapport ne doit pas préférablement depasser cinq ou une par page imprimée Les frais supplementaires necessités par des illustrations en couleur seront à la charge de l auteur Il n y aura pas de tires à-part gratuits Ils doivent être payés par l auteur

On recommande a tous les membres du Collegium de s abonner aux *Acta Oto Laryngologica* ou personnellement ou par l intermédiaire de leurs Instituts

L B W Jongkees

Der Herausgeber der *Acta Oto Laryngologica* wird hiermit beauftragt den folgenden Beschluß des Collegium O R L A S bezuglich Veroffentlichung der Collegium Verhandlungen bekanntzumachen

Alle bei den Sitzungen der Collegium O R L A S verlesenen Vortrage werden im Rahmen von *Acta Oto-Laryngologica* veroffentlicht und diese stellt die Verhandlungen Ehrenmitgliedern und Mitgliedern zu Das Collegium tragt mit 250 Pfund Sterling zu der Veroffentlichung der Verhandlungen einer Sitzung bei

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L B W Jongkees

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